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THE DEVELOPMENT OF SYSTEMATIC PETROGRAPHY IN THE NINETEENTH CENTURY.[1]

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SUMMARY.

Part I.

INTRODUCTION.

THE systematic and descriptive science of rocks — petrography — is a product of the nineteenth century. One hundred years ago the distinction had not yet been drawn between the rock and the geological formation or terrane, and many dense rocks were still included among minerals and described as such. With the discrimination between stratigraphic units and rocks proper the science of petrography became outlined, but did not at first receive a name. For some time after the proper scope of the science was clearly defined its development was rapid, and in certain later periods there have been notable advances, due to the invention of some new method of research or to the stimulation afforded by discoveries in some closely allied branch of science.

For the last thirty years or more research in all directions has added greatly to our knowledge of rocks, through the adaptation of the microscope to their study, improved methods of chemical analysis, and a vast store of accurate field observations of occurrence and relationships. But the systematic part of the science has not kept even pace, and does not adequately express the knowledge of the day. This lagging behind on the part of the classificatory branch of petrography is most natural, and similar conditions have existed in various epochs of the past. It is due partly to the necessity for a thorough consider-

ation of the store of new information concerning rocks before its true bearing upon classification could be correctly appreciated, and partly to prevailing differences of opinion as to the relations of petrography to the broader science of rocks — petrology.[1]

At the present time students in many parts of the world, dissatisfied with existing petrographic systems, are turning their attention to classification, and are attempting to apply the newly acquired knowledge, with or without the aid of theoretical considerations, to the construction of improved systematic arrangements of rocks. In view of this situation it has seemed appropriate to present at this time a review of the development of systematic petrography. An understanding of the steps taken in bringing the science to its present condition must certainly be useful to those who would assist in causing important advances in the future.

In this review no attempt will be made to give a complete historical sketch of petrography, but rather to study in a somewhat critical way the course of development through which the science has passed, to analyze the more important contributions to its advancement, and especially to examine the principles nominally applied in formulating schemes of classification and to test the methods of application as to their logical directness and consistency. From some cause the existing systems are commonly regarded as unsatisfactory and inadequate, and this condition indicates either that the principles of classification have not been wisely chosen or that they have been incorrectly applied.

That the standpoint of the reviewer may be clear, it may be

[1] The terms "petrology" and "petrography" have been so widely used in various senses that the writer wishes to urge an agreement among students of rocks to apply each in future in accordance with the scope implied in its etymology. On this basis the broad science or treatise of rocks is manifestly *petrology*, and the descriptive, systematic science, leading to the nomenclature of these objects, should be *petrography*. This usage corresponds to the definitions given in the "Lexique Pétrographique" prepared by F. Loewinson-Lessing, with the co-operation of many other petrographers, published in the *Compte Rendu of the Eighth International Congress of Geologists* (Paris).

well to state the principles which have guided him in his analysis of systematic propositions:

1. A systematic classification of rocks has for its object the arrangement of all rocks in groups according to a method, producing a regular subordination of parts. While in all classifications the groups must possess certain chosen characters in common, the system is natural or artificial according as the groups express community of fundamental, important characteristics, or of comparatively unimportant properties, chosen for convenience only.

It is commonly admitted that rocks are incapable of truly natural classification, but that the nearest possible approach to a natural system is to be desired. It is, therefore, important to scrutinize systematic propositions to see if their factors of classification have a fundamental connection, making the sequence of divisions natural in desirable degree. Each factor applied should have important natural relations to those preceding and following it in construction of the system. The writer thus believes that the classification of systematic petrography should be a *hierarchical classification*, in distinction to the *cross-classification* necessary in petrology.

2. A systematic classification must be logical in construction. Whatever principles or criteria the architect of a system may adopt, he must be logically consequent and consistent in their application, else his structure is weak, and must fall.

3. It is unscientific to use an assumption which is known to be untrue as a basis of classification.

4. An adequate system of petrography must be stable and comprehensive. In order to fulfil these requirements it must be based upon knowledge, not upon theory or hypothesis; it must be created for *all rocks*, known or unknown, of the characters now understood; its framework must be capable of change in detail without injury to the structure as a whole.

5. The use of ignorance concerning the constitution of some rocks as a factor for their classification is no longer permissible.

If, in the comments to be made upon various systems, it

appears to the reader that those of the present day are more severely criticised by the writer than those of earlier periods, it must be remembered that such a discrimination is natural and just. With greater knowledge of rocks, and with the experience of earlier systematists to guide him, the petrographer of the present day should be able to present a classification freer from defects than any proposed by his predecessors. It is the writer's aim to avoid all personal animus in discussion of the existing systems of classification.

Petrography may be concisely defined as the systematic classification of rocks. But if the principal handbooks of today be referred to, it will be found that it is a matter of supposed mutual understanding, rather than of precise statement, as to what constitutes a rock. It is commonly said that rocks are masses of geological importance in the constitution of the earth, but no very serious attempt is made to define what is of importance, or to discuss what treatment shall be given to substances excluded under such a definition. For the purposes of this review, it will be sufficient to define rocks as the *substances constituting* masses of geological importance, recognizing that geological units of mass are not necessarily units in constitution, and may change in material character from place to place. It is the task of petrography to furnish a systematic arrangement of these natural objects and a corresponding nomenclature. The geologist may wish to consider rocks from many different standpoints, each requiring a more or less special grouping and appropriate terms to express the observed or assumed relationships, and such groupings may be apart from systematic petrography.

VIEWS OF ROCKS BEFORE THE NINETEENTH CENTURY.

The category of rocks as understood today is somewhat different from the categories conceived to be the subject-matter of petrography in various epochs of the past. The early history of petrography is therefore in large degree a history of the differentiation of the sciences dealing with various categories of

the mineral kingdom — mineralogy, stratigraphic geology, and petrography. But while a complete review of the subject must note the origin and application of the ideas by which this differentiation was brought about, it is more particularly the object of this retrospect to trace the development of classification, beginning with the time when it was first sought to distinguish a group of objects even approximately corresponding to rocks as at present understood. A brief consideration of the earlier stages is, however, necessary to a clear understanding of the conditions existing in the first decade of this century.

Linnæus.— Certain gems and ornamental stones were known to the ancients by names which they bear to this day; but no attempted classification of the mineral kingdom prior to the time of Linnæus, in the middle of the eighteenth century, need be considered at this time, nor is the system of Linnæus of much importance except for the framework of the classification he proposed for the mineral kingdom, the same which he applied with so much greater success to the organic world. It has been said of Linnæus that he had a talent amounting to a genius for the arrangement of natural objects according to system; that "He found biology a chaos; he left it a cosmos." But he extended his *Systema Naturæ* to cover the inorganic world from a logical desire to reorganize the entire field of natural history, rather than from an intelligent knowledge of rocks and minerals.

In the Linnæan system the first grand division of the mineral kingdom is into Petræ, Mineræ, and Fossilia; but an examination of the substances arranged under these heads shows that the system expresses great ignorance as to the character and relations of many objects classified. Doubtless the followers of Linnæus, who were many and enthusiastic, were stimulated to much research as to the character of rocks and minerals, in their efforts to arrange them within the system of their master; but the most visible effect of the Linnæan system was to furnish a theme for controversial debate and argument for a century to come. The attempt to force inorganic substances into the same scheme of species, genera, etc., provided for plants and animals

was warmly advocated on the one hand, and as fervently denounced on the other.

Development of mineralogy.— The latter half of the eighteenth century witnessed great advances in knowledge concerning the materials of the earth's crust, and toward its close there began to crystallize out of that knowledge the three sciences of mineralogy, geognosy, and petrography, although the latter was long unnamed.

With more and more accurate information as to the constant chemical composition of minerals, and under the influence of Haüy's brilliant conception of molecular structure and crystal form as attributes of these substances, mineralogy rapidly advanced to its place as a definite branch of science. Its subject-matter grew more and more homogeneous by a process of exclusion, as it became clear that many composite or impure substances had been erroneously classified with minerals. But the mineralogist of this period of development had little interest in and paid little attention to the heterogeneous aggregate of objects rejected from his category. Nevertheless mineralogists considered rocks as so plainly forming an appendix to mineralogy that they set up schemes for their classification based almost wholly upon mineral composition.

Foundations of petrography.— While mineralogy was thus developing on definite lines, the students of the mineral masses observed to have wide distribution in the earth were building up a vastly more complex science. By the careful researches of Pallas, de Saussure, von Buch, von Humboldt, Werner, Smith, Macculloch, and many others, the generalizations upon which stratigraphic geology is based were being formulated. The facts of an order in the superposition of strata were established in several localities and the genius of Werner was devoted to the framing of hypotheses explaining the observations made and providing for the extension of generalizations to the rock masses of the globe.

The foundations of petrography were laid in this period, the term rock (*roche*, *Gestein*) was frequently employed, and works

termed classifications of rocks were published before the nineteenth century began. Thus in 1787 appeared Karl Haidinger's *Systematische Eintheilung der Gebirgsarten* (Vienna) and A. G. Werner's *Kurze Classification und Beschreibung der verschiedenen Gebirgsarten* (Dresden). The former essay, though awarded a prize by the St. Petersburg Academy of Sciences, appears based upon a superficial knowledge of rock masses when compared with the Wernerian arrangement. In these and other contemporaneous systems it is plain that the geological formation was not distinguished from the rock, as we now use these terms, and hence there was no true petrographical scheme at this time.

Werner's classification of rock formations.—Werner devoted much careful study to the mineral composition and general characteristics of rocks, and often described them in appropriate and precise terms. He distinguished between *simple* and *compound* rocks, and recognized that in many cases certain minerals were to be considered as *accessory* as compared with other *essential* constituents. Perhaps more than any other geologist he laid the foundations of *descriptive* petrography, but his systematic arrangement was so predominantly devoted to expressing a supposed order of superposition of rocks in the earth that it was rather a crude stratigraphic scheme than a classification of rocks which he presented. This will be clear from the outline given below.

Werner applied the term "formation" to masses of a certain character originating under certain conditions and perhaps recurring at various times in the history of the earth. Formations were grouped according to the great periods of their origin. He distinguished:

1. Primitive formations (*Das Urgebirge*): Under this head are found granite, gneiss, mica schist, clay slate, limestone, quartzite, porphyry, pitchstone, serpentine, and many other formations.

2. Transition formations (*Das Uebergangsgebirge*): Here were placed clay slate, graywacke, greenstone, gypsum, etc. The oldest fossils were supposed to occur in these rocks.

3. Stratified formations (*Das Flötzgebirge*): In this division are found sandstone, stone coal, marl, rock salt, various limestones, chalk, basalt, amygdaloid, and other formations.

4. Alluvial formations (*Das aufgeschwemmte Gebirge*): Here occur sand, clay, gravel, etc.

5. Volcanic rocks (*Vulkanische Gesteine*): This includes only lavas and ejectamenta of volcanoes, with several pseudovolcanic substances.[1]

The great majority of igneous and metamorphic rocks, as we now term them, were believed by Werner to be of aqueous origin, and were treated as such. In Werner's mineralogical system many rocks also found a place, as appears in von Kobell's statement of his system as it was in 1798. For example, under the clay family (*Thongeschlecht*) are included, among others, pitchstone, clay slate, basalt, wacke, clinkstone, lava, and pumice.[2]

DEVELOPMENT OF SYSTEMS IN THE NINETEENTH CENTURY.

At the beginning of the century, then, the attempts at the systematic classification of rocks were progressing on two very different lines. On the one hand the mineralogist, treating rocks as an appendage to mineralogy, was arranging them primarily by their mineral constitution, as far as he could determine it, and was for the most part uninfluenced by considerations of geologic origin or occurrence. His system was founded upon the most obvious characteristics of the objects in question.

On the other hand, the geologist was hampered by his efforts to arrange in one system geological terranes (formations) and rocks proper. He could not logically apply any criterion throughout the system, and was most inclined to use geological occurrence and theoretical considerations of origin.

The geologist's early classifications of rocks were naturally more complicated and less logically and consistently carried out than the schemes of mineralogists, and were correspondingly

[1] This general statement of Werner's elementary system I have taken principally from A. VON ZITTEL'S *Geschichte der Geologie und Paleontologie*, 1899, p. 89.

[2] F. VON KOBELL, *Geschichte der Mineralogie*, 1864, p. 165.

less satisfactory. But no classification of this period could have been really adequate, because the chemical and mineralogical compositions, as well as the origin, of many rocks were unknown, and only modern methods of research have permitted the assignment of a large number of types to their proper relationships.

Abbé R. J. Haüy.—The first systematic arrangements of rocks to be of much importance to the science of petrography as now understood were evolved in Paris, and the controlling idea of these systems has dominated French petrography for a century, and is evident in all systems to some extent.

The Abbé R. J. Haüy was professor of mineralogy at the Museum of Natural History in Paris and in charge of its great cabinet of minerals. As already mentioned, his conception of molecular structure and its relation to crystal form had placed mineralogy within its proper sphere. In 1801 he published the first edition of his classic work "*Traité de minéralogie*," in four octavo volumes, with a fifth of quarto-size containing eighty-seven plates, filled for the most part with figures of crystals. This treatise is evidence at once of the advanced state of mineralogy and of the non-existence of anything worthy of being termed a science of rocks, in France, at this time. The quarto-volume of the *Traité* contains a tabular view of Haüy's "Distribution Méthodique des Minéraux." To this elaborate system of minerals are added two short appendices presenting an arrangement of rocks. One is headed "Agrégats des différentes substances minérales," the other, "Produits des Volcans." That the arrangement of rocks had not received much thought from Haüy at this time is clear from the imperfect scheme presented and from the fact that it was not until 1811 that Haüy addressed a letter to Leonhardt's *Taschenbuch für Mineralogie*, saying that he had conceived the idea of classifying rocks mineralogically ("J'ai conçu l'idée de classer cette suite (des roches) minéralogiquement").

Haüy was not a geologist, and his system must be judged in the light of the circumstances under which it was constructed. These are trenchantly characterized by Lossen in his comment

that "the idea of mineralogical classification, of this great contemporary of Werner, did not spring from a wealth of geognostic observations; his letter [above referred to] was not dated from the central plateau of France, from Vesuvius, from the Rhone Valley, or from Predazzo, as were the classic letters of Leopold von Buch at an earlier day, but from the mineralogical cabinet in Paris.[1] Furthermore, the enlargement of the halls allotted to the collections and the consequent rearrangement of the latter was the immediate inspiration of the idea. Haüy's system is therefore characterized by Lossen as cabinet specimen petrography.

The writer does not know whether or not Haüy's revised system was actually published prior to the appearance of the second edition of his *Traité de minéralogie* in 1822. As there presented, it expressed at least ten years' development under the idea announced in 1811. Its principal feature is: a subdivision of rocks into classes, orders, genera, species, varieties, and modifications. Five classes of rocks are distinguished, viz.: (I) Stony and saline; (II) Combustible nonmetallic; (III) Metallic; (IV) Rocks of an igneous origin according to some, aqueous according to others; (V) Volcanic rocks. This grand division is clearly not logical or consistent. General, chemical, and physical properties and mode of origin are all arbitrarily applied. The stony appearance used to produce the first class is recognized as possessed also by the questionable igneous rocks of the fourth class, and is the first factor used for their further subdivision. A "schist inflammable" is included in the first class in spite of the property applied to produce the second class. Except for the class of metallic substances Haüy's category of rocks is similar to that now recognized as the subject-matter of petrography; that is, he did not include with them geological formations, as did many of his contemporaries.

The inconsequent construction of this system appears also in

[1] K. A. Lossen. "Über die Anforderungen der Geologie an die petrographische Systematik." *Jahrbuch der königl. preuss. geolog. Landesanstalt und Bergakademie*, 1883.

the factors used to produce three orders under the first class, viz.: (I) Phanerogenous ("phanerogène"); (II) Adelogenous ("adélogène"); (III) Conglomerate. The rocks of the first order are made up of definite mineral species, and their composition is apparent. The composition of those of the second order is not apparent to the naked eye, and it is assumed that portions of them do not belong to mineral species. Further, it is stated that some of them are clastic; but why these are not placed in the third order, which is defined as containing rocks composed of cemented particles of older rocks, is not discussed.

The "cabinet petrography" of the mineralogist, as Lossen characterized it, is still more evident in the formation of genera, which in the first class, embracing the largest number of rocks, are named after minerals. The first genus is Feldspar, including not only rocks consisting mainly of feldspar, but also granite, syenite, pegmatite, protogine, gneiss, etc. Similarly, diorite is a species under the genus Amphibole. Haüy's system has always been criticised as giving entirely undue weight to certain minerals; but unnatural as is his scheme in that respect we have the same idea with us today, although it is no more logical now than it was a hundred years ago.

The criteria used in subdividing genera and species in Haüy's scheme are mainly those deemed of *primary* importance by later authorities. The *simple* and the *composite* are the leading heads under the genus, and structure is used to form varieties or modifications under the species.

John Pinkerton, 1811. — In 1811 there appeared in London a pretentious work of 1200 pages entitled: *Petralogy, a Treatise on Rocks*, by John Pinkerton, an Englishman. The author was an eccentric character, whose claim to renown rests rather on his historical researches than on his *Petralogy*, for he clearly had little conception of the objects under discussion in that work. The greater part of Pinkerton's energy was directed to a quaint and prolix argument against the tendency of the time to classify mineral substances in the same manner as animals and plants. His *bête noire* was the mineral *species*, for he insisted that the

essential element of the species in the animal or vegetable kingdom was its power to "produce a similar progeny."

Dr. Jameson tells us [remarks Pinkerton] that there is in fact but *one* species in mineralogy, namely, the globe; but even this may be doubted till it shall have produced another, at least as round and as wicked.

Admitting as appropriate the fundamental division of natural history into three kingdoms, the animal, vegetable, and mineral, Pinkerton ingeniously draws a distinction.

In the two former [he remarks] the kingdom consists of living subjects, who, of course, may be well considered as divided into classes, orders, genera, and species; but in the mineral kingdom the territory alone constitutes the subject of discussion.

But the very term mineral kingdom may of itself lead to a new and more proper nomenclature; for as a kingdom may be regarded as either vivified with animal and vegetable life, or as an inert tract of country, with certain geographical, chorographical, and topographical divisions; so the latter point of view can alone apply to mineralogy, while the former belongs to zoölogy and botany.

What is more usual than the division of a kingdom into provinces, districts, domains, etc.? I would propose, therefore, in the present advanced state of the science, that the mineral kingdom be considered as divided into three Provinces:

1. Petralogy, or the knowledge of rocks, or stones which occur in large masses.
2. Lithology, the knowledge of gems and small stones.
3. Metallogy, or the knowledge of metals.

Petralogy, a Province of mineralogy [is then] divided into twelve *Domains;* of which the first six, being distinguished by the substances themselves, may be called *substantial;* while the remaining six, being distinguished by circumstances or accidences of various kinds, may be called *circumstantial* or *accidential;* but this last division is of little moment.

The six "substantial" domains of Pinkerton are:

1. The Siderous, in which iron predominates.
2. The Siliceous.
3. The Argillaceous.
4. The Magnesian.
5. The Calcareous.
6. The Carbonaceous.

The "accidential" domains are:

7. The Composite.

8. The Diamictonic, "in which substances are mingled."

9. The Anomalous, "or those which contradict the common order of nature."

10. The Transilient.

11. The Decomposed.

12. The Volcanic.

This outline will indicate sufficiently that the *Petralogy* has no real importance to the present review. Pinkerton does not appear to have been taken seriously by his contemporaries, as there is little or no reference to his elaborate system in succeeding publications of his countrymen.

Alexandre Brongniart, 1813.—In 1813 Alexandre Brongniart[1] published a *Classification minéralogique des roches mélangées*. The writer has not seen the original, but von Leonhard gives a tabular view of the scheme proposed by Brongniart, which shows it to have been crude, and not worthy of special discussion here, because of the much more elaborate and mature work by this author issued a few years later, to which some space must be given. But comparatively crude as this outline was, it gave much evidence of the logical mind of its author.

P. L. A. Cordier, 1815.—Contemporaneously with the constructive labors of Haüy and Brongniart, another French master was also struggling with the same problem. It is to the painstaking researches of P. L. A. Cordier that we owe the first great step in deciphering the composition of volcanic and other rocks of such fine grain that their constituents could not be recognized by the simple methods of examination then in use. He instituted chemical, microscopical, and mechanical researches of much ingenuity, and arrived thus early at the conclusion that volcanic rocks were made up of known minerals in microscopic crystals or grains, and of glass, which he believed contained the same elements. In 1815 Cordier presented to the Academy of Science in Paris the results of his investigations in an important work upon the substances composing volcanic rocks.[2] The

[1] *Journal des Mines*, Vol. XXXIV.

[2] P. LOUIS CORDIER, "Mémoire sur les substances minérales dites *en masse*," etc., followed by "Distribution méthodique des substances volcaniques dites *en masse*,"

classification of volcanic rocks accompanying his memoir was limited to the few surface lavas then known and the tuffs and ashes. He had the idea that either feldspar or pyroxene predominated in all cases, and hence the first division was into feldspathic and pyroxenic rocks. Texture was the main property applied for further subdivision.

John Macculloch, 1822. — The third decade of the century witnessed the publication of several important essays in rock classification. The first of these was by John Macculloch, and was entitled *Geological Classification of Rocks, with Descriptive Synopses, Comprising the Elements of Practical Geology*, issued in London, 1822. Macculloch's work is called "a classification of rocks," but it is really a classification of rock formations, as we should now express it. It is an attempt at stratigraphic geology without recourse to fossils. Its foundation was a knowledge, which was very thorough for the time, of the rocks of a limited area, and the assumption that the same rocks must, in general, occur in all parts of the world in the same sequence and relations as in the British Isles. In discussing the basis of his scheme he says:

> In considering the different plans on which a classification of rocks might be constructed, he (the author) was, without hesitation, led to adopt one founded on the geological relations and positions of rocks in nature . . . . the basis of the arrangement is virtually the same as that adopted by Werner.

Macculloch thought that all rocks might be placed in a few groups, distinguished by certain prevailing mineral characters.

> It will be further seen [he says] that these different groups are also in a great measure distinguished in nature by certain general or geological relations, more or less constant and perfect.

The arrangements according to mineral characters and geological relations were believed to coincide.

The attempt to use fossils as criteria of the age of rock formations, which was then being made by the Germans, did not appeal to Macculloch. He is said to have been jealous of the

Journal de Physique, 1815–1816. Both memoir and table of classification were reprinted by D'Orbigny in 1868, in his work *Description des roches*, etc., which gave the system of Cordier as elaborated at the time of his death, in 1861.

rapidly developing science of palæontology. In his opinion fossils were not well enough known, as to their kinds or their distribution, to be used as factors in classifying rocks as to their geological position. He says, however, that he looks forward to the time "when a system of organic mineralogy will be formed."

With regard to his system Macculloch remarks:

> The classification is simple; all rocks being referred to a primary and a secondary class, and a smaller division being formed of those which are found in both. The substances which cannot be referred to the latter class, from their more recent origin are considered separately in an *appendix;* and a similar expedient is adopted for the volcanic rocks.

"Primary" means to Macculloch anterior in date to the secondary; and "secondary" means later than the primary. Each class is divided into two divisions, the *Stratified* and the *Unstratified*. "As these subdivisions," remarks the author, "have not yet been introduced into any of the arrangements of rocks, they will each require some explanation."

The result of Macculloch's scheme is expressed in the following tabular arrangement of rocks:

PRIMARY CLASS.

Unstratified.

Granite.

Stratified.

Gneiss.	Red sandstone.
Micaceous schist.	Argillaceous schist.
Chlorite schist.	Diallage rock.
Talcose schist.	Limestone.
Hornblende schist.	Serpentine.
Actinolite schist.	Compact feldspar.
Quartz rock.	

SECONDARY CLASS.

Stratified.

Lowest (red) sandstone,	Limestone.
Superior sandstones.	Shales.

Unstratified.

Overlying (and venous) rocks.	Pitchstone.

OCCASIONAL ROCKS.

Jasper.	Gypsum.
Siliceous schist.	Conglomerate rocks.
Chert.	Veinstones.

Appendix.

Volcanic rocks.	Alluvia.
Clay, marl, sand.	Lignite.
Coal.	Peat.

If we examine this table, it is seen that Macculloch was not able to carry out consistently the application of the factors adopted. This is most conspicuously the case with the "overlying (and venous) rocks" placed in the unstratified division of the secondary class. These overlying rocks were, in fact, recognized as later than the secondary rocks in many cases. They are mainly what we should call intrusive igneous rocks, found cutting other rocks, and of the real age of which Macculloch confessed that he had little evidence. He was ignorant of the composition of aphanitic or felsitic rocks, and they receive no consistent treatment at his hands.

Macculloch is credited with having been a keen observer and with having made truly great contributions to stratigraphic geology. But he does not appear to have conceived of the distinction between a geological formation and a rock. There are in his book many phrases, such as the title of the work itself, and statements scattered through it, which are couched in the language of today, but have very different significance at this time. It is interesting to apply many of his remarks concerning the condition of the systematic science of rocks, as understood by him, to the petrography of today.

Karl Cæsar von Leonhard, 1823.—In 1823 appeared a truly epoch-making work, the *Charakteristik der Felsarten* by Karl Cæsar von Leonhard, professor at the University of Heidelberg. This is, in fact, the first fairly consistent treatise upon rocks. It is founded upon an exceptionally accurate knowledge of the objects classified, and with advanced ideas as to the true relations between geognosy proper and the descriptive science of

rocks. Yet von Leonhard did not give his science a name, and presents it as a part of geognosy.

Von Leonhard says that his object is to present all facts bearing upon the *character* of rocks, an aim expressed in his chosen title. He points out that a discussion of the stratigraphic relations of rocks must be preceded by an accurate statement of their nature. Rocks are defined as the mineral masses of more or less considerable extent in the crust of the earth. It is recognized that, from the standpoint of geognosy proper, only those masses can be considered important the extent of which is so considerable that general laws as to their relations and distribution may be discerned. Yet it is pointed out that there are other masses of subordinate or abnormal occurrence which may have a wide distribution, though occupying no position peculiar to themselves, and that these masses are important when arranged by their characteristics. Stratigraphic geology and petrography are thus fairly outlined, though no definite proposal for their separation is made.

The classification presented by von Leonhard has many features which are preserved in modified form in the German systems of today. Like all early systems, however, the primary division is arbitrary, and drawn upon no definitely stated principle. Four divisions are established: (1) Heterogeneous rocks, (2) Homogeneous rocks, (3) Fragmental rocks, (4) Loose rocks, while coals are placed in an *appendix*. For subdivision, structure is used as the basis, the granular, schistose, porphyritic, dense, and glassy groups being established in some of the main divisions. These terms are used with nearly the meaning we now attach to them. The principal anomalies of association in the arrangement arise from the throwing together of igneous and sedimentary rocks in certain groups, and from the inconsequent way in which von Leonhard met the difficulty of dealing with the more or less dense rocks, the composition of which could not then be ascertained. These were mainly of igneous origin, and not stratigraphic units, and there was no proper place for them in the system. They were treated as a group by them-

selves under the Homogeneous rocks, with the heading, "Rocks (apparently homogeneous) which are not to be regarded as minerals" ("Nicht als Glieder oryktognostischer Gattungen zu betrachtende—scheinbar gleichartige—Gesteine"). Here we find trachyte, aphanite, serpentine, basalt, pitchstone, obsidian, and various schists. Von Leonhard realized more or less clearly that most of these rocks would some day be found to be complex in character, and he therefore appreciated that his treatment of them was a makeshift. Twelve years later, in his *Lehrbuch der Geognosie und Geologie*, he raised the *apparently homogeneous* rocks to an equal rank with the heterogeneous and homogeneous divisions.

Von Leonhard was unquestionably the foremost petrographer of his day, sharing with Alexandre Brongniart the honor of first placing the classification of rocks upon a firm basis as a systematic science. He had been called to Heidelberg but a few years before this work was issued, finding there perhaps the largest collection of rocks then in existence. He had also visited Paris and studied the great collection of the Museum of Natural History as arranged by Haüy. Von Leonhard also belonged to the group of German geologists who, with Smith and Macculloch in England, and a few elsewhere, were engaged in placing stratigraphic geology upon a sure foundation. He did not himself develop the distinction, clearly foreshadowed in his work, between the geological formation and the rock.

A critical examination of the system contained in the *Charakteristik* shows that von Leonhard actually applied as his first criterion the distinction between massive and clastic rocks, as we should express it, though he may not have realized it. Next he applied the idea of homogeneity and its opposite. But the notable feature is the prominence given to structure and the close approximation of some of his definitions to ones in current use. It was the first time structure was assigned so prominent a rôle in a system of rocks. Mineral composition followed structure, and was applied quite reasonably.

The system of von Leonhard is specially noteworthy as the

work of a German, for in it he breaks away from the influence of the Wernerian school. This was doubtless to some extent the result of a visit to Paris, but while building upon the characteristics of rocks he did not give to mineral composition the completely dominating place which it held in the French systems. Von Leonhard rejects the biological framework of classes, orders, genera, and species as quite inapplicable to rocks, since they lack individuality.

Alexandre Brongniart, 1827.—The *Classification et charactères minéralogiques des roches homogènes et hétérogènes*, by Alexandre Brongniart, published in 1827, marks the next important step in the development of petrography. This admirable little book of only 144 pages contrasts markedly with other voluminous works of its period. It is concise in statement, and presents a clearly conceived and logically worked out system.

In the introduction we find minerals, rocks, and geological terranes distinguished and defined. *Minerals* are species or varieties determined by the laws of mineralogy; *rocks* are the same substances considered in their masses and as entering into the structure of the globe; *terranes* are assemblages of several rocks, considered as having been formed at about the same epoch. Brongniart pointed out that there were two ways of looking at rocks—as to their composition, and as to their occurrence. He held that geognosy was not strictly a classification of rocks; that to arrange rocks by occurrence and describe them in that order involved many digressions from the discussion of relationships; that rocks formed at different times must then be referred to as many times as they occurred; that the same name would be given to different substances formed at the same time; and, finally, that classification by occurrence involved the use of hypotheses where knowledge was lacking. All these troubles should be avoided, in his opinion, by classifying and naming rocks upon mineralogical composition and independently of occurrence. The treatment from the latter standpoint could then follow naturally.

The system of Brongniart is a mineralogical classification

with the aid of the exterior characters. His divisions are styled classes, orders, genera, and species. There are but two classes, viz.: (1) "Roches homogènes ou simples;" (2) "Roches hétérogènes ou composées." In this respect Brongniart is more logical than von Leonhard. The *Homogeneous rocks* are defined as those that *appear to be so* to the naked eye. There are two orders under the class of *Homogeneous rocks*, namely: (1) "Roches phanérogènes (of distinct known mineral species); (2) "Roches adélogènes" (of unrecognizable constitution). This division is logical enough, but it is based on a criterion of primary value which is clearly applicable to *all* rocks. The result is that under Homogeneous rocks are included, in the second order, a number of substances, including clays, dense schists, trap, basalt, and other igneous rocks, of really heterogeneous character.

The Heterogeneous rocks are also divided into two orders: (1) "Les roches de cristallisation; (2) Les roches d'agrégation." This distinction really introduces the factor of conditions of origin, which fact Brongniart seemingly did not recognize, as he makes no comment upon it.

When it comes to finer subdivision we find that this system is almost purely mineralogical, as its title claims. Structure is relegated to a very subordinate rôle, wherever it is convenient to apply it.

Systems of von Leonhard and Brongniart compared.—If we now review the construction of the systems proposed by von Leonhard and Brongniart, which may be taken as the real starting point of systematic petrography, we find that both resorted at once to an expedient which expressed the fact that in their day the composition of many rocks was unknown. And the principal inconsistencies of the two arrangements came from their treatment of the aphanitic rocks of all kinds throughout the schemes. But we must admit that these substances could not be correctly classified by composition so long as their character was so nearly unknown.

Both these masters relied mainly on *mineral composition*, but

von Leonhard advanced *structure* also to a prominent place. Both declared that the system and nomenclature of rocks should be founded upon *characteristics*, and that the various treatments rocks must further receive from the geologist would be facilitated rather than retarded by such an arrangement. Brongniart made a suggestion, apparently unconsciously, in subdividing Heterogeneous rocks, that geological conditions of origin might serve as a practical basis in classification; but he made only limited application of that factor, and does not appear to have grasped the broader meaning of his own proposition.

After von Leonhard and Brongniart had placed petrography upon a firm basis, no great advance was made in the systematic part of the science until the middle of the century. The cause of the unsatisfactory elements in the early schemes was recognized to lie in the ignorance concerning the character of many rocks, and a large number of investigators devoted themselves to the study of the composition of rocks on the one hand and to their geological relations on the other. While the object of this review is to trace the application of principles or of knowledge in classification rather than to follow the course of investigation, it is necessary to refer briefly to the studies made during the second quarter of the century, noting the use of new knowledge in system.

Investigations into the chemical composition of rocks.— Among the characters of rocks not taken into appropriate account in the first systems, by far the most important is *chemical composition*. But from the beginnings under Cordier more and more attention was paid to chemical investigation, until other things became quite subordinate. First, qualitative test was applied, then partial analysis, and finally bulk analysis. Chemical research was naturally applied with most valuable results to the denser rocks, chiefly of igneous origin, and in this way, with ever-extending field investigation, it was found that these substances were vastly more complex, more varied in character,

and much more common than had been supposed. From these causes the petrography of igneous rocks grew to be the principal part of the science instead of being relegated to an "appendix," as had been done at an earlier day.

The chemical analysis of igneous rocks was mainly directed to a determination of their mineral constituents and to the question as to whether the various oxides were present in simple or constant proportions or not. For the latter inquiry the ratio of the oxygen contained in the silica to that of the bases, taken together or in groups, was calculated and comparisons instituted. G. Bischof set up as a means of comparison the so-called "oxygen quotient," obtained by dividing the total oxygen of the bases by that of the silica, as shown in the analysis of any given rock. That the faulty analyses of the time could not in any case have yielded trustworthy evidence of stoichiometric or constant proportions of the constituents is now clear; but even with the imperfect analyses the complexities of the problem were such as to lead nearly all chemical students of rocks to abandon attempts to deduce chemical formulæ or simple ratios for them.

For many years chemical investigations were necessary in determining the approximate mineral composition of many rocks, and important discoveries were undoubtedly made; but it is pathetic to recall the years spent in hard labor by many of the foremost men of their time in endeavoring to work out the mineral composition of fine-grained or aphanitic rocks from incorrect or inadequate bulk analyses, and with very imperfect knowledge of the constitution of some rock-making minerals. Abich, Bunsen, von Waltershausen, Bischof, Scheerer, Roth, Streng, Delesse, Haughton, and many others devoted much time to this research without what appears to us, at this time, to have been commensurate results.

Classification by feldspars.—The principal effect of this chemical work upon petrographic classification appears to have been to perpetuate the mistake of giving an undue importance to the feldspars as rock constituents. As different kinds of feldspar

were recognized by chemical analysis, largely through the researches of Gustav Rose, a further mistake was made. It was for a time thought that orthoclase (or potash feldspar), albite, oligoclase, labradorite, and anorthite were the only feldspar species entering into rocks, and that they did not occur to any great extent in association. Hence, after setting up a great division of *feldspathic rocks*, the logical method for subdivision was according to the kinds of feldspar present. This was thought to be the more surely a correct principle, since its application seemed to produce groups nearly coinciding with those previously recognized, but less sharply defined.

Perhaps the first to advocate the use of feldspars in this way was Hermann Abich, in 1841.[1] Abich viewed magmas as basic, neutral, or acid silicate solutions of a great range in specific gravity. As the known feldspar series presented also a wide range in silica and in specific gravity, it seemed to him certain that there must be a definite relation between the silica content of a given magma and the feldspar which could crystallize out of it. It therefore seemed to him possible to use the various feldspars for the classification of endogenous (or eruptive) rocks very much as fossil remains were used in sedimentary rocks. For the next twenty-five years a sharp division according to feldspars was advocated, in systems to be reviewed; and it required the application of the theory of isomorphous mixtures to feldspars, the polarizing microscope, and modern methods of mechanical and chemical analysis, to demonstrate the true distribution of feldspars in rocks, and the thoroughly artificial nature of this arrangement.

Influence of genetic hypotheses.—The connection of chemical composition of igneous rocks with theories as to the origin of the differences in composition of magmas and the use of the genetic conception in classification forms an interesting chapter in the history of systematic petrography. Yet the application of this genetic idea led at first only to a broad and ill-defined

[1] H. Abich, *Geologische Beobachtungen über die vulkanische Erscheinungen und Bildungen in Unter- und Mittel-Italien*, Braunschweig, 1841.

proposition in classification which does not require full discussion in this place. Reference is had to Bunsen's hypothesis of two fundamental magmas—the trachytic and the pyroxenic—mixtures of which were supposed to produce all igneous rocks.[1] From the systematic standpoint Durocher's hypothesis had the same result, though differing somewhat from Bunsen's in the physical origin of the magmas. Durocher (1857) carried out a chemical division of igneous rocks on his hypothesis, forming the *acid*, *hybrid*, and *basic* groups.[2] Th. Kjerulf[3] (1857) proposed four chemical groups: *acid*, *neutral*, *basic*, and *ultra-basic*, and various authors recognized the grand division of *acid* and *basic*. Such divisions, when closely connected with hypotheses, have had more influence upon the geologist than upon the systematic petrographer; for it was quickly found that, although the fundamental idea might be near the truth, the theory was too imperfect (or narrow) to explain the observed range in chemical composition of igneous magmas. The broad chemical distinction, considered merely as a recognition of the observed range in composition of rocks, was not given sufficient precision to be of much value in system.

Geological classifications.—During these years of patient research, especially into the composition of igneous rocks, geologists were making important contributions to the broader phases of classification. As a knowledge of occurrence, relation, and modes of formation of rocks increased many different factors were tested as to their applicability to the formation of systematic arrangements. Soon the numerous geological standpoints from which rocks might be viewed and classified led to a great many schemes for their arrangement, and much confusion existed. This condition continued until the geologist separated the systematic classification of rocks from various other arrange-

[1] R. BUNSEN, "Ueber die Processe der vulkanischen Gesteins-bildungen Islands," *Poggendorf's Annalen*, etc., Vol. LXXXIII, 1851, pp. 197–272.

[2] J. DUROCHER, "Essai de pétrologie comparée," etc., *Annales des Mines* (5) Vol. XI, 1857, p. 217.

[3] *Nyt magazin for naturvidenskaberne*, Vol. IX, 1857, p. 294.

ments of which these bodies were found capable. Certain geologists, as, for instance, De la Beche in England, had, at an early day, very clear and logical ideas as to the principles which must control classification. In the third edition of his *Geological Manual*, issued in 1833, is the sentence: "Classifications of rocks should be convenient, suited to the state of science, and as free as possible from a leading theory." In accordance with this principle, De la Beche divided all rocks (including formations) into *stratified* and *unstratified*, "independent of the theoretical opinions that may be connected with either of these great classes of rocks." The stratified rocks were then subdivided into "superior or fossiliferous" and "inferior or non-fossiliferous." By this logical division De la Beche at once secured classes or subclasses corresponding well to those now called igneous, metamorphic, and sedimentary.

Carl Friedrich Naumann, 1850, 1858.—Without attempting a complete history of the introduction of each factor into classification, we will now consider the system of Carl Friedrich Naumann, the great Saxon geologist, as of much importance in presenting *a new mode of treatment*. The first edition of his *Lehrbuch der Geognosie* appeared in 1850, the second in 1858. Naumann was a great systematist; he viewed rocks from many standpoints, and from each constructed a peculiar scheme of treatment. Thus one section of the *Geognosie* was called "Petrographie oder Gesteinslehre," defined farther as a branch of "Chthonographie oder die Geognosie im engeren Sinne des Worts." This is the first use of *petrography* of which I have knowledge. It is used in the sense of petrology, as the latter term is now commonly applied in America.

Naumann not only gave the comprehensive science of rocks a special name, but he established within it six divisions, namely:

A. Hylology, a discussion of the constituents of rocks.
B. Histology, on texture and structure of rocks.

C. Morphology, a classification of forms of occurrence.
D. Synopsis, or the systematic descriptive science.
E. Petrogeny, a discussion of the genesis of rocks.
F. Allo-osology, the science of the alteration of rocks.

Under this elaborate framework rocks were grouped in many ways. They were considered as minerogenous, zoögenous, or phytogenous, according to origin of materials; as crystalline, clastic, dialytic, or amorphous, depending on character of the constituent grains; as simple or composite; in another view as phanomeric or cryptomeric, and so on.

But when it came to the systematic arrangement of his "Synopsis" Naumann was at sea. He himself called it an *attempt* at a grouping of rocks—"Ein Versuch einer Gruppirung der Gesteine"—and plunged without discussion of principles into the description of rocks under a scheme of classes, orders, families, and lesser divisions.

In the first edition of the *Lehrbuch*, Naumann divided all rocks into three classes, namely: (1) Crystalline rocks; (2) Clastic rocks; (3) Rocks which are neither crystalline nor clastic.

It was explained that the groups of amorphous, zoögenous, and phytogenous rocks are scarcely co-ordinate in importance with the crystalline and clastic divisions, so they were united in the third composite class. In the descriptions of the Synopsis, however, the amorphous (hyaline and porodine) rocks were considered in connection with the rocks of the other two classes to which they are related in composition.

In the second edition but two classes were recognized, embracing all rocks: (1) Protogenous (original); (2) Deuterogenous (derived). Naumann gave no discussion of the basis upon which he made the change.

In both editions Naumann leaves the manner of subdividing classes to the reader to make out for himself. In the class of original rocks are six orders, viz.: (1) Ice, (2) Haloid rocks, (3) Quartz rocks, (4) Silicates, (5) Ores, (6) Coal. Families are produced within these orders by mineral composition. Structure,

texture, and other properties are occasionally used for minor unnamed divisions. After the elaborate preparation for this arrangement, it must be confessed that Naumann failed utterly to produce a system worthy of the name. No logical and consequent application of principles can be found in his Synopsis.

The great value of Naumann's work lies in the clear setting forth of the scope of the *general science* of rocks, independently of their formal or historical relations to the earth. He outlined the divisions under the broad science, and showed the proper position of the purely systematic and descriptive branch. He illustrated clearly how many arrangements or groupings of rocks are natural and necessary from the geologist's standpoint, and evidently understood that he could not introduce all these considerations into the construction of one system of classification.

In the development of petrographical system, Naumann's analysis of the broad science was of great importance. For many years the primary classification of rocks, leading to an arrangement for purposes of description, followed some of the various ways set forth by him. And even at the present day we find H. Credner, a successor of Naumann in the university at Leipzig, presenting rock descriptions in his well-known *Elemente der Geologie* under a framework very similar to that of the *Lehrbuch der Geognosie*. Whatever the choice of criteria adopted by individuals from among the alternatives presented by Naumann, very similar, if not identical, major divisions were formed.

Bernhard von Cotta, 1855, 1862.—Almost contemporaneously with Naumann's *Geognosie* appeared several other treatises on rocks by German authors of note. *Die Gesteinslehre*, by Bernhard von Cotta, was first published in 1855, and its second edition in 1862, the latter being translated into English and serving for years as a standard work.

The first edition of the *Gesteinslehre* professes to be merely a description of rocks, and the arrangement or order in which the various kinds are presented is stated to be one of convenience only. Von Cotta's point of view was that, as rocks are simply aggregates of mineral particles, one kind grading into another,

and as they are of different modes of origin, there can be no species comparable to those of plants, animals, or minerals, and hence a classification, properly speaking, is an impossibility. Reviewing the various characters of rocks as to their application in nomenclature and description, this author touches on some fundamental points with noteworthy discrimination. This is particularly true with regard to his remarks on the availability of texture for purposes of classification. Noting that it is the most easily distinguished character of rocks, and that it had been used as a primary factor in classification, he pointed out that chemical and mineral composition were more fundamental, and that there was nothing so intrinsically important in texture that differences in that respect should be allowed to separate things otherwise alike.[1] It seemed to him better to name the rock from its mineral composition, and for textural varieties to add expressive terms.

In this first edition of the *Gesteinslehre*, von Cotta introduced no geological factor into his adopted arrangement. He treated all rocks in the following groups, which were purely for convenience :

1. Basaltgesteine.
2. Grünsteine und Melaphyre.
3. Trachyte.
4. Porphyre.
5. Granite und Gneisse.
6. Glimmerschiefer.
7. Thongesteine.
8. Kieselgesteine.
9. Kalksteine und Dolomite.
10. Gypsgesteine.
11. Verschiedene Mineralien als Gesteine.
12. Eisengesteine.
13. Kohlen.
14. Trümmergesteine.

In the second edition of the *Gesteinslehre*, issued in 1862, while still claiming rocks to be incapable of true classification by inherent characters, von Cotta makes a noteworthy advance toward a systematic arrangement by grouping them primarily according to geological mode of origin. As further factors he uses, in certain classes, broad chemical distinctions and form of occurrence. His general scheme is as follows :

[1] "Genau genommen ist indessen die Textur gar nichts so wesentliches, dass sie veranlassen könnte, wegen ihrer Ungleichheit zwei Gesteine ungleich zu nennen, wenn sie übriges gleich sind."—*Gesteinslehre*, p. 22, 1855.

I. Eruptive rocks, probably all originating through consolidation from a molten condition.
   1. Poor in silica, or Basic.
      a. Volcanic.
      b. Plutonic.
   2. Highly siliceous, or Acid.
      a. Volcanic.
      b. Plutonic.

II. Metamorphic crystalline schists, probably all derived from sediments, yet resembling eruptive rocks in mineral composition.

III. Sedimentary rocks.
   1. Argillaceous.
   2. Calcareous.
   3. Siliceous.
   4. Tuffs.

To these three clearly defined groups was added an appendix of rare rocks or those of problematic origin. Here were included many quartzose rocks, coals, iron ores, serpentine, etc.

The eruptive rocks were considered as derived from molten magmas; the broad chemical distinction was made with Bunsen's law in mind, but not directly as its expression; the volcanic and plutonic rocks were separated purely on the basis of occurrence; the further subdivision was by general mineral composition, and texture was used as subordinate to it. It is worthy of special note that von Cotta expressly pointed out that geological age was not involved in the distinction between the volcanic rocks and the plutonics. He considered that the older volcanics had been largely removed by erosion, and that the younger plutonics had not yet been laid bare.

Ferdinand Senft, 1857.—In 1857 appeared an elaborate work by Ferdinand Senft, with the title (translated) *Classification and Description of Rocks, Founded upon their Mineral Constitution, Chemical Composition, and Structure.*[1] This treatise, which received the Demidoff prize (St. Petersburg), is mainly notable for its elaborate attempt to apply chemical factors in details of classification.

[1] "Classification und Beschreibung der Felsarten, gegründet auf ihre mineralogische Beschaffenheit, ihre chemische Zusammensetzung und ihre Structur," Breslau, 1857.

In this work Senft gives detailed tables for the determination of rocks, the first of which presents the following general scheme of classification :

A. Inorganic rocks ("Anorganolithe").
  I. Crystalline.
    1. Simple.
    2. Composite.
  II. Clastic.
    a. Indurated.
      1. Pseudoclastic.
      2. Hemiclastic.
      3. Holoclastic.
    b. Unconsolidated.
      1. Gravel, sand, etc.
      2. Soil ("Erdkrumer").
B. Organic rocks.

Curiously enough Senft's discussion of principles of classification begins with the consideration of the means for subdividing the smallest divisions of this table, which he calls "Classes."

Senft believed that rocks of these classes should be further arranged by their characters. Reviewing these, he points out the great difficulties in so classifying them, owing to the fine grain, variable composition and texture of many kinds. The facts lead him to assert that the main systematic divisions, such as orders, groups, etc., cannot be founded on structure (Gefüge) or other outer habit of the rocks, because the former factor would at once separate similar things, and the latter bring different things together. Mineral composition would be the best basis for arrangement were it not for the fact that, in the fine-grained or aphanitic rocks, chemical tests are necessary to determine the mineral components. As it is, the chemical relation of rocks—and especially of the crystalline—to certain solvents affords the only safe means by which rocks can be classified. This factor of solubility is actually applied to the formation of orders, suborders, and groups under the classes provided by the scheme already outlined. Senft is, however, not fully consistent, for the first division of the class of composite crystalline rocks is on mineral composition, into the two

orders: (1) Alabradorites (rocks free from labradorite, generally rich in quartz, and never containing augite); (2) Labradorites (rocks characterized by labradorite and free from quartz and orthoclase). These were subdivided into nine groups, according to the action of hydrochloric or sulphuric acid upon the rocks. For further details of this unique and highly artificial system the reader must be referred to the original work.

J. Reinhard Blum, 1860.—Shortly after the treatises of Naumann, von Cotta, and Senft, there was published the *Handbuch der Lithologie oder Gesteinslehre*, by J. Reinhard Blum.[1] This work is but little more than a descriptive handbook, with slight discussion of principles of classification, and in it no original contribution to the systematic science was made. The main divisions of the work are as follows:

I. Crystalline rocks.
  A. Homogeneous.
    a. Granular.
    b. Schistose.
    c. Porphyritic.
  B. Heterogeneous—with three structural divisions.
II. Clastic rocks.
  A. Cemented.
  B. Not cemented.

The further division of crystalline rocks is by mineral composition.

Justus Roth, 1861.—Among the students of the chemical composition of igneous rocks none has rendered greater service than Justus Roth, who, in 1861, published his *Gesteinsanalysen, in tabellarischer Übersicht und mit kritischen Erläuterungen.* Upon the basis of nearly a thousand analyses available at that time, Roth undertook to ascertain whether chemical composition gave in itself a practical ground for the classification of igneous rocks. As a basis for comparison of analyses Roth selected the oxygen ratio, *i. e.*, the ratio of the oxygen of the acid radical, SiO_2, to that of the bases, RO (including R_2O) and R_2O_3, and obtained

[1] *Erlangen*, 1860, pp. 356.

the oxygen quotient (originally proposed by Bischof) by dividing the oxygen of the bases by that of silica.

Comparing all available analyses in this way Roth recognized that no simple chemical relations existed between different rocks, and that chemical formulæ were therefore useless; that rocks of different mineral composition fell in the same chemical division; that chemical and mineral arrangements of rocks could not coincide; that a purely chemical arrangement would separate things closely related on geological and mineralogical grounds; and that a mineralogical arrangement must be connected with structure and texture. In this dilemma Roth chose to arrange igneous rocks primarily by their kinds of feldspar and the presence or absence of quartz. He admits that pyroxene or amphibole might be used in the same way, but considers feldspar much preferable because of its greater abundance and easier determination. The scheme of classification presented by Roth is as follows:

I. Orthoclase rocks (often containing some oligoclase).
  A. With quartz (*i. e.*, more siliceous than orthoclase).
    1. Granite.
    2. Gneiss.
    3. Felsite porphyry.
    4. Liparite.
    5. Syenite.
  B. Without quartz.
    1. Orthoclase porphyry.
    2. Sanidine trachyte.
    3. Sanidine-oligoclase-trachyte.
    4. Phonolite.
    5. Leucitophyre.

II. Oligoclase rocks.
  A. With hornblende.
    1. Diorite.
    2. Porphyrite.
    3. Amphibole andesite.
  B. With augite.
    1. Oligoclase-augite-porphyry.
    2. Melaphyre and spilite.
    3. Pyroxene-andesite.
    4. Nephelinite.
    5. Haüynophyre.

III. Labradorite rocks.
  1. Labradorite-porphyry.
  2. Gabbro.
  3. Hypersthenite.
  4. Diabase.
  5. Dolerite.
  6. Normal pyroxenic rock (Bunsen.)
  7. Basalt.

IV. Anorthite rocks.
  A. With augite — eukrite.
  B. With hornblende.

This arrangement attempts no expression of a relation between chemical and mineral composition; it assumes constant

presence of feldspars in some amount in all rocks, and also certain characteristic associations of minerals. It indirectly recognizes structure and geological age as factors in classification. Roth believed that the classification by mineral components outlined certain combinations or associations as central points of notably frequent and widespread occurrence, about which the rocks of other combinations and of comparative rarity must be grouped. While expressing the idea that not only the kind but the amount of various minerals might be considered in a mineral classification, he confined his own adaptation of this idea to the recognition of *essential* and *accessory* constituents, in certain cases, and with no definite plan.

Th. Scheerer, 1864.—Shortly after the appearance of Roth's tables of rock analyses, a proposition for the general classification of igneous rocks upon a chemical basis was published by Th. Scheerer.[1] This proposition is notable as representing the views of one of the men who, in the preceding decade, had devoted much time and labor to the bulk analysis of rocks. Unlike Roth, who had come to the belief that no simple and persistent chemical formulæ or ratios could be set up for igneous rocks, Scheerer was convinced that he had found such formulæ, and that all silicate rocks could be referred to nine comparatively simple chemical types.

Upon the basis of earlier investigations of the gneisses of the Saxon Erzgebirge, Scheerer had come to the idea that all of them could be considered as mixtures of three magmas, represented in nearly pure form in three prevalent gneisses of the region, namely: the "Rother Gneiss," "Mittlerer Gneiss," and "Grauer Gneiss," the composition of which might be expressed in simple formulæ, given below. The visit to the Fassathal was made to test the general applicability of this threefold division to other highly siliceous rocks, and to gather from the numerous basic rocks of that region material for chemical

[1] "Vorläufige Bericht über krystallinische Silikatgesteine des Fassathales und benachbarter Gegenden Südtyrols," *Neues Jahrbuch für Mineralogie*, etc., 1864, pp. 383–411.

investigations which might show the feasibility of classifying all rocks in a similar manner.

Upon scrutiny of his material and study of analyses of rocks from other localities, Scheerer was persuaded that all highly siliceous igneous rocks could be referred to the three magmas represented by the Saxon gneisses above mentioned, or to mixtures of these magmas. The intermediate and basic rocks he believed could in a similar manner be assigned to six definite chemical types, and in the cited publication Scheerer outlined this chemical classification.

Scheerer's system expresses the idea that the molten material below the solid crust is arranged by specific gravity in zones, each of quite simple stoichiometric composition. He further believed that the upper, more siliceous magmas were first erupted, and the basic ones in late geological periods. From this cause the earliest rocks might be supposed to represent the fundamental magmas more nearly than the basic ones, since the latter magmas must have passed through rocks of varied constitution in reaching the surface, and, therefore, suffered much modification through the fusion and assimilation of fragments torn loose in ascending.

The nine chemical types of Scheerer were arranged in three groups, and named from rocks deemed to represent them in purest form.

	Oxygen Ratio $SiO_2 : RO + R_2O_3$ (= 1).	Oxygen Quotient.	Mean silica Percentage.
PLUTONITES:			
Upper = "Rother Gneiss".....	4.50	0.222	75
Middle = "Mittlerer Gneiss"....	3.75	0.267	70
Lower = "Grauer Gneiss".....	3.00	0.333	65
PLUTO-VULCANITES:			
Upper = Quartz-bearing syenites.	2.67	0.375	63
Middle = Syenite.....	2.33	0.429	60
Lower = Melaphyre.....	2.00	0.500	55
VULCANITES:			
Upper = Augite-porphyry.....	1.50	0.667	48
Middle = Common basalt.....	1.33	0.750	42
Lower = Basic basalt.....	1.00	1.000	36

The "Rother Gneiss" corresponded to Bunsen's "normal trachytic" magma, and the augite-porphyry to the "normal pyroxenic" magma.

The primary divisions of Scheerer are obviously very nearly the same as Durocher's acid, hybrid, and basic groups. The types themselves seem to have been established under the control of a genetic theory, and contrary to the evidence afforded by the tables of rock analyses published by Roth three years before the appearance of Scheerer's proposition. The latter does not refer to the conclusions reached by Roth, which were so directly opposed to his own.

Ferdinand Zirkel, 1866.—Shortly after the works by Roth, von Cotta, and Scheerer there appeared (1866) a work which may be taken as well representing the stage of development of petrographic system in Germany at the beginning of what may be called the era of the microscope. This work is the *Lehrbuch der Petrographie*, by F. Zirkel, who was to be one of the master spirits of following decades.

This treatise was, and, indeed, still is, a mine of useful information to the student, and its contribution to the systematic science was of much influence. Zirkel's elementary scheme of classification is the following:

A. Original crystalline rocks ("Ursprüngliche krystallinsche").
I. Simple rocks ("Einfache Gesteine").
II. Composite rocks ("Gemengte Gesteine").
    1. Composite crystalline-granular and porphyritic rocks ("Gemengte krystallinisch-körnige und Porphyr-Gesteine").
    2. Composite crystalline-schistose rocks ("Gemengte krystallinisch-schieferige Gesteine").
B. Clastic rocks ("Klastische Gesteine").

This arrangement has elements drawn from various sources. In the grand division into original and clastic (secondary) Zirkel followed Naumann, but returned to von Leonhard for the criterion of the second order. In rejecting von Cotta's system, based on mode of origin, Zirkel remarked that this plan would be highly satisfactory were it not founded upon hypothetical considerations. He secured divisions closely corresponding to

von Cotta's eruptive, sedimentary, and metamorphic classes by roundabout means.

In his arrangement of original simple rocks, Zirkel practically followed Naumann.

In the *Lehrbuch* igneous rocks were given the greatest attention. They were brought together in one group by applying three factors at once, as *composite crystalline-granular and porphyritic rocks*. In practice the noncrystalline or vitreous rocks were also included here. This inconsequent proceeding was necessary to bring the eruptive or igneous rocks together, a fact demonstrating that the chosen method of primary subdivision was logically incorrect. The first subdivision of this group was by relative age into the *Older* and *Younger* rocks, a distinction which Zirkel himself recognized was highly artificial.[1] He pointed out that rocks of certain characters had actually received different names, according to age, although the time factor had not been used in their systematic arrangement; and he chose to be logical in application of that factor, to agree with usage, rather than to eliminate the duplicate terms. Had he chosen the latter alternative it is safe to assert that much of the still existing confusion from unnecessary duplicate rock names might have been avoided.

In further systematic subdivision mineral composition and texture were used in ways which have been followed more or less closely by many petrographers to the present time. Following Roth and others it was first determined to consider all rocks of the groups in question as *feldspathic* or *non-feldspathic*. Feldspathic rocks were held to include all in which feldspars or feldspathoids were present in appreciable amount. By this course two very unequal divisions were created and the qualitative element of mineral composition was confirmed in its position of dominance over the quantitative, which has had such unfortunate influence upon systematic petrography to this time.

The plan of forming a great group of feldspathic rocks may have appeared to be desirable on account of the belief, long since

[1] *Lehrbuch*, Vol. I, pp. 446, 447.

shown to be erroneous,' that four kinds of feldspar, namely, orthoclase, oligoclase, labradorite and anorthite, seldom occurred together, and therefore might be used to characterize four great series of rocks. The feldspathoids were used to define another large series.

It appears that in this proposition to use qualitative mineral composition as a leading factor in classification, as in that to apply the age distinction, Zirkel merely gave definite expression to the growing usage of the time, which was practically found in other systems, though not so clearly avowed as a principle. The effect of his proposition to apply geological age and this qualitative element of mineral composition as leading factors in the systematic arrangement of the rocks we now term igneous was peculiarly unfortunate, because this invaluable work of reference was issued at the beginning of the era in which petrographers were to be so busily engaged in the microscopical study of rocks that they had no time for systematic work. In the flood of descriptive literature of the succeeding decade these propositions were adopted almost of necessity. The students from all lands who flocked at this time to Germany to study under Zirkel and other masters, carried the system back to their respective countries, giving it quickly a world-wide usage.

Ferdinand von Richthofen, 1868.—Shortly after the appearance of Zirkel's *Lehrbuch* a philosophical discussion of the classification of igneous rocks, as viewed from the geologist's standpoint, was published by the distinguished German traveler and geologist, Ferdinand von Richthofen. This essay was written and published during an extended visit in the United States, under the title "Principles of the Natural System of Volcanic Rocks."[1]

Von Richthofen calls systematic petrography "the most intricate branch of descriptive natural science." He characterizes the earlier systems as artificial, because based upon the idea "that classification should be made dependent on one certain principle previously assumed as the point of issue." The prin-

[1] *Memoirs presented to the California Academy of Sciences*, Vol. I, pp. 39–133, 1868.

ciples especially named as used in this way are, crystalline texture, lack of stratification, predominance of silicates, etc. To von Richthofen it appeared that the exact mineral composition of rocks as a basis for their classification had become possible after the investigations of Gustav Rose on the feldspars, and that by this means petrography had been brought out of a chaotic state. While acknowledging, therefore, the high value of mineral composition as a basis for classification of igneous rocks, von Richthofen considered that its exclusive application had grouped rocks geologically far separated, and distinguished rocks geologically closely connected, which seemed to him a fundamental error.

The "natural system" of igneous rocks proposed by this author was based upon the Bunsen law of two fundamental magmas, and upon what he considered to be demonstrated facts of a broad correlation between developed texture and age of igneous masses, and of an order of succession of magmas in the history of the earth. By using "eruptive" as a collective term for all rocks under discussion, he implied the adoption of geological mode of origin as the first principle in classification. Von Richthofen remarked that Bunsen's law might have to be revised, "but no change of its principles may ever be expected, as an overwhelming amount of evidence has accumulated in support of its essential tenor." Texture is used by von Richthofen as the second principle in system to produce three classes of eruptive rocks: granite, porphyritic, and volcanic. He says that the conclusion appears to him to be justified "that the three great classes of eruptive rocks are geologically separated and represent three successive and distinct phases of the manifestation of subterranean agencies." The granites of the Sierra Nevada, with which he had personally become familiar, forced von Richthofen to admit that in some parts of the world the ancient granitic and porphyritic eras were succeeded by later eras of the same rocks, within the Mesozoic, but he believed that the volcanic era began with the Tertiary, both in Europe and America. The old lavas of the British Isles, known since the early decades of the century, were either disregarded or overlooked by him.

Mineral composition was regarded by von Richthofen as "essentially dependent on the chemical composition," and was used by him as "more articulate" than the latter, in the construction of his scheme. The outline of von Richthofen's systematic arrangement is as follows:

Eruptive Rocks:

Class I. Granitic Rocks.
Orders: 1, Granite; 2, Syenite; 3, Diorite; 4, Diabase.

Class II. Porphyritic Rocks.
Orders: 1, Felsitic Porphyry; 2, Porphyrite; 3, Melaphyr; 4, Augitic Porphyry.

Class III. Volcanic Rocks.
Orders: 1, Rhyolite; 2, Trachyte; 3, Propylite; 4, Andesite; 5, Basalt.

The further mineralogical variation of rocks was expressed in families under each order.

In this system three principles were applied: (1) Mode of origin; (2) A supposed fact of correlation between age and texture; (3) Chemical composition as represented in mineral composition, and practically expressing the author's belief in the Bunsen law.

While von Richthofen's system was not followed in its details by petrographers, some space has been given to it here because of its influence upon many geologists, perhaps especially in the United States, and because it illustrates so clearly the perils of introducing genetic ideas into the systematic classification of igneous rocks, even when those ideas are believed to be established as laws.

It may be mentioned here that von Richthofen enunciated practically the same views in his *Führer für Forschungsreisende*, issued in 1886.

Cordier's system and its influence.—Turning now to France, before taking up the essays at classification made during the era of the microscope, it appears at first thought strange that for thirty years after Brongniart's classic work no important

advance was made in the systematic classification of rocks in that country. And when a very significant advance was made, it appears not to have been recognized. The master spirit of French petrography during this period and until his death was P. L. A. Cordier. He was engaged until the end in carefully elaborating his system of classification, which was presented in lectures and applied to the great collection of the Museum of Natural History in Paris. Cordier does not seem to have published his classification himself, but it was made known by his associate, Charles d'Orbigny, in the *Dictionnaire universel d'histoire naturelle*, article "Roches," and others, Paris, 1842–1848; and in the volume *Description des roches*, etc., edited from the manuscript and lectures of Cordier, published in Paris, 1868, seven years after his death.[1]

The stagnation in systematic petrography in France during this period may be referred to two causes: First, the inherent weakness of Cordier's system; and, second, the traditional custom prevailing in France which gives to the recognized master in any branch of science a strongly dominant influence, which few are willing to openly oppose.

The weakness of Cordier's system came chiefly from the fact that it was, like that of Haüy, based too largely upon the convenient arrangement of cabinet specimens. Viewing rocks simply as aggregates of minerals, they were studied in detail, and their broad relationships were ignored, as belonging wholly to geology. In 1848, only two years before Naumann issued his philosophical analysis of petrography, and 33 years after Cordier published his own first scheme for the arrangement of volcanic rocks, his comprehensive system was announced by D'Orbigny, in the cited article of the *Dictionnaire universel*, etc., to have the following features:

Its fundamental idea was that the classification of rocks should be grouping of *species*, not a subdivision of the grand category of rocks. The species, based upon composition, was

[1] At an earlier date it was translated into German by Kleinschrod, in *Jahrbuch für Mineralogie*, 1831, p. 17.

regarded as a nearly constant mixture of certain elements and as characterized by a certain structure. Species were supposed to be much more numerous than the unimportant transition types—"roches du passage."

The rock species was determined almost solely on mineralogical grounds. Geological origin and occurrence were used merely as appropriate elements in the description of the species—stating its *habitat*, so to speak.

Species were grouped in genera according to the state of aggregation, as explained below. Orders were based upon the power of the eye to distinguish the character of the rock. The most important of the still larger groups, the family, was formed in most cases upon the *predominant mineral present*, and the families were grouped upon an indefinite chemical basis, in four classes, namely:

Class 1. Earthy rocks (roches terreuses).

Class 2. Saline or acid non-metalliferous rocks (Roches salines ou acidifères non métalliques).

Class 3. Metalliferous rocks (Roches métallifères).

Class 4. Combustible non-metallic rocks (Roches combustibles non métalliques.

Predominance of one mineral constituent, the quantitative factor applied to form families, the most important of divisions aside from the species, was assumed to mean: (1) more than half where two constituents were concerned; (2) more than one-third where three constituents were present, and so on. In complex rocks it was naturally difficult of application and was almost impossible in aphanitic rocks. Moreover, it was not adhered to strictly, as pointed out by D'Orbigny in regard to basalt, which was referred to the pyroxenic family although feldspar might really predominate over pyroxene. As D'Orbigny naïvely remarks: "But it is this latter substance which gives its character to the rock" (Mais c'est cette dernière substance qui donne son caractère à la roche).

The elaborate system of Cordier may be illustrated by the following section, giving the subdivisions within the feldspathic family:

Class I. Earthy rocks (Roches terreuses).
First family, feldspathic rocks (Roches feldspathiques).
1. Order. Phaneromeric — of which the constituents are visible to the naked eye (Phanérogènes dont les éléments sont visible a l'œil nu).
1. Genus. Aggregates (agrégées).
Species: (1) harmophanite, (2) leptynite, (3) gneiss, (4) pegmatite, (5) granite, (6) syenite.
2. Genus. Conglomerates (Conglomérées).
Species: (1) feldspathic breccia, (2) feldspathic conglomerate, (3) feldspathic grit and sandstone.
3. Genus. Unconsolidated sands, etc. (Meubles).
Species: (1) Feldspathic sands and gravels (sables et graviers feldspathiques), (2) pebbles and débris of feldspathic rocks (galets et débris de roches feldspathiques).
2. Order. Aphanitic — wholly or partially (Adélogènes en tout ou en partie — dont le volume des parties est en totalité ou en partie invisible).

Other families of earthy rocks are named after pyroxene, amphibole, garnet, hypersthene, diallage, talc, mica, and quartz. An inconsequent element in the construction of the system, found in various places, is illustrated in the eleventh family, vitreous rocks, introducing a new factor while stating that the rocks in question are *feldspathic*.

The great majority of known igneous rocks are assigned by this system to the aphanitic (adélogène) orders of the various families, because their constitution is not wholly determinable by the naked eye.

The system of Cordier was the system of France for years after his death, in 1861, and was published in elaborate form by D'Orbigny in 1868.[1] In all essential particulars the system had remained unchanged. At the beginning of the chapter upon the principles of classification is the declaration: "The description of rocks requires in advance: (1) the formation of species; (2) their classification" (La description des roches exige avant tout: 1° l'institution des espèces; 2° leur classification). There is so

[1] CHARLES D'ORBIGNY, *Description des Roches, etc.* Rédigé d'après la classification, les manuscrits inédits, et leçons publiques de P. L. A. Cordier. Paris, 1868.

little new in the construction of the system that no further analysis of it seems necessary.

No influence of Cordier's principles can be detected in modern systems for the classification of rocks. The importance of his system from the standpoint of this review lies in the retarding influence it exerted for several decades over the development of the science in the country where Brongniart had laid such logical foundations. But it seems to the writer that it was after all not so much the inherent weakness of Cordier's system as it was his domination over the thought of his countrymen, to a degree possible only in France, that retarded progress for so long. It is significant to recall that D'Orbigny's last presentation of the system appeared two years later than the *Lehrbuch* of Zirkel, but far more so to note, in confirmation of the opinion just expressed, that it was published eleven years after an important treatise on rocks, issued in Paris by a French geologist of renown, presenting a broad and logical view of petrographic system, which was not even referred to by D'Orbigny.

H. Coquand, 1858.—In 1858 there was published in Paris a work by H. Coquand, the title of which, translated, is as follows: *A Treatise on Rocks, Considered from the Point of View of Their Origin, Their Composition, Their Occurrence, and Their Use in Geology and Industry.* This book has over four hundred pages, and contains a classification of rocks very different from any earlier or contemporary scheme, but it has received very little recognition in spite of its merits. Coquand was professor of mineralogy and geology in the College of Besançon. Possibly he did not belong to the distinguished coterie of Parisian geologists, and in that case the fact that he should come out with a system full of originality, strongly opposing that of Cordier, who was still alive, may have been regarded by his contemporaries as such a flagrant violation of unwritten law that the only course open to them was to ignore his proposed scheme of classification.

The title of Coquand's treatise shows at once how completely he had broken away from the traditions of his countrymen. His classification has little in common with other French systems,

and, if not wholly original, one must suspect the dominant influence of Naumann's views. Its main outlines are as follows:

Three families of rocks are recognized:

I. Igneous rocks.
II. Aqueous rocks.
III. Metamorphic rocks.

Igneous rocks are divided into three groups:

1. Granitic (in the sense of granular).
2. Porphyritic.
3. Volcanic.

Aqueous rocks into three groups:

1. Chemical deposits.
2. Mechanical deposits.
3. Carbonaceous rocks, of vegetable origin.

Metamorphic rocks into three groups:

1. Crystalline schists.
2. Those of chemical origin.
3. Those of mechanical origin.

It will be seen that this system is in its outline wonderfully like many of recent years in its logical use of factors in construction, and in the order of their application. In further subdivision, finally producing species, Coquand was less fortunate, being governed still by the mineralogical idea too closely. Probably he was much less fitted for the descriptive task than Cordier, who doubtless surpassed him in intimate knowledge of the detailed characters of rocks as cabinet specimens; but he certainly possessed a logical mind, and grasped far better than his contemporaries the relations of petrography to geology.

Archibald Geikie, 1872.—Turning to the literature of other countries during this period, it is evident that systematic petrography was developed as a science almost wholly through the labors of workers in Germany and France. Prior to the microscopical era, soon to be considered, practically no special students of this subject appeared in either Great Britain, America, or in other countries. Aside from the discussions of geologists, like De la Beche, already mentioned, there was in Great Britain no important contribution after the time of Macculloch. The

conditions in that country up to 1870 may be summarized by the statements of Archibald Geikie, in 1872, in the *Students' Manual of Geology*. He there says: "There is as yet no good English treatise on petrography, or the classification and description of rocks." In this work all rocks are first classified "under the four great heads of igneous, aqueous, aerial, and metamorphic, according to the nature of the agencies by which they have been brought into their present state and position." "Igneous rocks without exception are composed of minerals which are silicates. These minerals may be said to belong to two great classes: silicates of magnesia and silicates of alumina," each combined with other bases. "The felspars are the bases of all truly igneous rocks, those in which no felspar or mineral of that type is present being very few and unimportant, even if they exist at all." Here we see the proposition made by Zirkel stated in extravagantly positive terms.

Igneous rocks are divided into volcanic, trappean, and granitic, with crystalline and fragmental subdivisions under the first two. The trappean class is vague and "of convenience only." In the volcanic class the law of Bunsen is practically recognized and two groups established: "the trachytes, or felspathic or acidic group," and "the dolerites, or pyroxenic or basic group." Similar groups are formed under the trappean class. The granitic class embraces only granite and syenite.

WHITMAN CROSS.

(To be continued.)

NEOCENE DEPOSITS OF THE KLAMATH REGION, CALIFORNIA.

Description.— In the Klamath region west of the Sacramento River, chiefly in Trinity county, there are several deposits of alluvial gravel and sand which seem to correspond to the auriferous gravels or "high-level channels" of the Sierra Nevada region. They were first mapped in 1892 by Diller[1] as Neocene deposits, and correlated with the Ione formation. Four separate areas are known within Trinity county, one in the old valley of Trinity River between Trinity Center and Junction City, another in Hay Fork valley, the third in Indian Creek valley, and the remaining one in Hyampour valley. Doubtful remnants may occur near Lowden's ranch and Big Bar on Trinity River.

These deposits occur in valleys of erosion, trenched deeply into the hard metamorphic rocks. The distinguishing characteristics of the old or Neocene valleys are (1) their great width compared with the Pleistocene valleys; (2) their flat bottoms; (3) their abrupt termination at both ends; and (4) their usually containing remnants of Neocene channel deposits. The writer is familiar with three of these valleys and will describe them in some detail.

Scott valley, in Siskiyou county, has a length of about twenty miles and an average width between three and four miles. Its direction is north-south and it lies between parallel ranges of mountains of which that on the west consists of very resistant formations, including micaceous quartz, schist, serpentine, and granodiorite, and attains a general elevation above the valley of four thousand feet. The range on the east is not nearly so high, owing to the formations composing it being the rather soft slates of the Devonian and perhaps Carboniferous. The valley itself is trenched largely into these slates, but reaches serpentine and the older schists beneath them. Undoubtedly the unusually great

[1] *Fourteenth Annual Report of the U. S. Geol. Surv.*, Pl. XLV.

width of this valley is due to the rather soft nature of the formations, but the fact remains that all other valleys of this region carved into the same formations are relatively narrow and have the gulch form, which, in the Klamath region, is the characteristic of the Pleistocene valleys.

Scott valley terminates as abruptly at the northern or downstream end as at the other, and Scott River drains it through a narrow gorge which is only partly explained by the hardness of the formations cut into. This valley has no known Neocene remnants, as its floor is so elevated (about three thousand feet above the sea) that subsequent erosion may have completely removed them. Its identification as Neocene rests on its large size and its abrupt termination at both ends.

The Hay Fork valley, in southern Trinity county, has a length of about eleven miles and an average width between one and two miles. Its course is a little south of west, or obliquely across the strike of the formations, which here occur in parallel belts as they have been folded and faulted. The strata of the metamorphic rocks stand at a high angle, usually approximating to the vertical. The flat floor of the valley has an altitude at Hay Fork village of about 2,200 feet above tide and the surrounding mountains rise to an average height of about 4,000 or 4,500 feet above the sea. The valley is, therefore, quite a deep trench and a prominent feature of the topography. Its walls are comparatively steep. The form of the valley shows distinctly that it is the result of ordinary stream erosion. There would be nothing remarkable about this valley if it were not that it is the only one of the kind in that portion of the country. All the neighboring valleys are relatively narrow and of the gulch type. Hay Fork stream enters the valley on the south about four miles from its eastern end, coming out of a narrow, gorge-like valley. Above this point the Hay Fork valley is occupied by an insignificant stream which seems out of place in the large valley. As there is nothing in the structure to explain the great contrast in size and shape of the valleys, we naturally conclude that the broad Hay Fork valley belongs to a separate and older system.

To what extent this valley may have been filled up by alluvial action we do not know, as, since its elevation, erosion has nearly reopened it, and the Neocene deposit within it appears merely as a small remnant. It seems to be continuous from end to end, and back of Hay Fork village forms a sort of terrace, occupying the north half of the valley and rising about sixty feet above the present stream level. It consists chiefly of layers of fine gravel and sand, indicating ordinary alluvial action. Near the upper end of the valley, interstratified with the gravel, I have found at least one bed of a white chalky material which seems to be rhyolite tuff, and Anderson reports this material from other parts of the formation. Near the lower end of the valley, where the deposit of gravel occurs in the bed of Hay Fork Creek, the stream exposes layers of lignite. It is the presence of this impure coal and the supposed tuff which postulate a pre-Pleistocene age for the deposit and the valley in which it occurs.

Hay Fork valley is terminated at the western or downstream end by a sudden narrowing of the valley of the Hay Fork Creek, which drains the old valley through a deep rocky gorge (said to be a veritable cañon), not to be explained by an increase in that direction in the resistant properties of the metamorphic formations.

Before discussing the Neocene deposit of the Trinity River, which is in many respects the most interesting and instructive of these old river channels, it will be necessary to direct attention to one of the most salient points in the later history of this region. This is the abandonment by the Trinity River of its original course, between Trinity Center and Junction City, and the excavation by it of a new valley roughly parallel to the old, and distant from it on the average about five miles. The new course is southeast of the old, on the outer side of a curve and consequently considerably longer than the original course. The two valleys are separated by a rock ridge of no mean height. The new valley is comparatively narrow and of the gulch type, although its floor in places has a width of one-fourth to one-half mile.

Now, on the direct line between Trinity Center and Weaverville, and thence to Junction City, there is a distinct basin or broad valley, three or four miles in average width, and partly floored by another of the Neocene River deposits. The general altitude of this basin is toward the north, about 3,500 feet above the sea, or 1,300 feet above neighboring portions of the present Trinity River. Examined in detail, the present floor of the basin is found to be quite uneven. Since the abandonment of this course by the Trinity River, streams which issue from the high mountains on the west, and formerly joined the main river in the basin, now continue across it and transect the rock ridge beyond, and have cut cañons or narrow valleys in the floor of the basin. A large part of the surface has been reduced much below the original level. So far as the channel deposit is concerned, only two limited portions of it are regarded as preserving essentially the original surface.

On the west of the basin rise abruptly to altitudes of seven and eight thousand feet, the bare rugged peaks of the Sierra Costa Mountains. The Trinity range on the east is much lower, and it is difficult to fix the original line between the basin and these mountains.

The old channel deposit is continuous from a point about one mile south of Swift Creek to the La Grange hydraulic mine on Oregon Mountain, between Weaverville and Junction City, a distance of twenty miles. It lies along the western edge of the basin, at the foot of the high mountains. Northward from Weaverville, it is known through its exposure on the sides of the deep transverse valleys, to occupy a deep valley about one mile in average width, and having remarkably steep walls, a veritable cañon. This cañon seems to be an old valley of erosion, which was completely filled with alluvial gravel and sand, giving the Neocene deposit a great thickness, which is one of its remarkable features.

We have no data for determining the actual thickness of the deposit, but we can fix upon a mininum in the latitude of Buckeye Mountain, a few miles northeast of Weaverville. Buckeye

Mountain is a ridge of gravel transverse to the course of the channel. Close by on the north, Stewart's Fork River has cut a valley across the old channel to the depth of 1,600 feet, without reaching the bottom of the gravel. On the southwest, a well in Weaverville is said to have penetrated over 600 feet of gravel and sand before reaching the metamorphic rocks. At least 1,000 feet in thickness of the deposit was removed in the erosion of Weaver basin. A thickness of the old channel deposit of 1,600 feet is a very conservative estimate. On Oregon Mountain the La Grange mine exposes 500 feet in depth of these gravels. North from Stewart's Fork several streams, Stope Creek and the East Fork of Stewart's Fork, have cut transverse valleys through the old channel to a depth exceeding 500 feet, and have not reached its bottom. That its thickness is abnormally great for an alluvial deposit needs no further evidence.

Lithologically, the formation is just an ordinary river gravel, irregularly stratified in the manner common to such deposits. The pebbles, cobbles, and small bowlders are very plentiful, and have been derived from the metamorphic rocks of the neighborhood. The predominating species in any section is that of the bordering terrane. Below the zone of oxidation the color is a deep blue, but higher, yellow and buff predominate, and at the surface there is a deep staining of bright red. There is much clay among the gravel, in places gathered into separate layers.

At the mouths of certain valleys which issue from the high mountains on the west, as, for instance, Stope Creek and the East Fork of Stewart's Fork, northwest of Minersville, after the completion of the main deposit, it was covered by alluvial fans remarkable for the immense bowlders, largely of granodiorite, which are thickly packed in them. So old are these deposits that all the bowlders are decayed, and a ditch or a fresh natural section, as a recent landslide, shows merely their outlines, and never a projecting rock — that is, the bank is smooth, like a clay or sand bank. On the main channel deposit near its original surface, there are no bowlders or cobbles scattered about, all

having disappeared by decay, but deep in the formation the cobbles are comparatively fresh.

The age of this deposit is considered to be the same as that of the Hay Fork, Indian Creek and Hyampour, because it is of similar lithologic character, occupies a similar valley, and has suffered great erosion since its abandonment by Trinity River. No coal is known from this area, and no tuffs have with certainty been discovered in it. No bones or fossil plants have yet been reported from it. However, it has not been closely examined for them, and even the tuff may occur and have escaped notice.

Conditions of accumulation. — Several interesting problems are presented by the old Trinity River deposit. What were the conditions which caused the accumulation of 1,600 feet of alluvial gravel and sand? Why did the river abandon its old course and cut a new valley on a longer course?

Let us first inquire into what fixed the site of the old valley. The abrupt southeastern face of the Sierra Costa Mountains on the west side of the old Trinity valley has the appearance of a degraded fault scarp. After long consideration of the matter, I have concluded that while there may be an old fault on this line, it has had very little influence on the present topography. It is along this line that the resistant serpentine and granodiorite of the higher mountains meet the rather soft and easily eroded Bragdon slate and the Clear Creek volcanic series, the Mesozoic representatives in this region. The mountains on the west are high because the rocks are very resistant, and those on the east are low because the rocks are softer. Along the junction between the two areas was a line of unusual weakness, perhaps because of an old fault, and that controlled the Trinity River between Trinity Center and Weaverville. In the course of time the river varied somewhat from the fault(?) line, and at one place cut its deep cañon entirely on the serpentine side of the line. This strengthens its interpretation as a valley of erosion.

The accumulation of 1,600 feet of gravel and sand by river action could have occurred under one of only two conditions; either a depression of the land to a lower level relatively to sea

level, or the local sinking of an orographic block bounded by faults, such as Professor Whitney adduced in explanation of Yosemite Valley. Dr. A. C. Lawson has called to my attention that in Europe, particularly in Germany, there are depressed areas of no great width which clearly have resulted from a "dropping out of the bottom," as we may say. The flat bottoms, steep walls, and canoe shape of the valleys occupied by the Neocene deposits in Trinity county seem to favor this theory, but against its adoption I have the following objections :

1. Outside of the four or five Neocene valleys already mentioned, there is no evidence in Trinity county of Neocene or later faulting. We know there have been gentle disturbances, broad arching of the strata, but no general breaking up of the rocks. The faulting would have to be strictly localized or confined to these valleys. Where the faults intersected at the corners of these valleys they must have terminated abruptly, not gradually dying out as is the habit of faults.

2. The valleys trend in different directions, so that there could be no regularity in the system of dropped fault-blocks, as there usually is.

3. The old Trinity valley is rather too crooked, and the crooks are not systematic enough to fit into such a scheme of dropped fault blocks.

4. The coarse character of the deposit throughout the Trinity area shows that the valley was kept filled up to a river level during a progressive sinking, and had there been a sinking of the rock floor relative to the walls, the gravel deposit should in its lower portions be much disturbed and bent up along the borders, a structure which has not yet appeared in the deepest natural or artificial excavations.

5. But the strongest objection of all lies in the fact, which may be particularly observed in the case of the old Trinity valley, that these valleys do show the influence on their width of the varying resistant properties of the formations traversed. The northern portion of the old Trinity valley is narrow (averaging one mile) because it is trenched into serpentine and the

Clear Creek volcanic series, both relatively resistant. In the Weaver basin it entered an area of the Abrams mica schist, which observation elsewhere has shown to be one of the less resistant formations, and here the valley widened out to three and four miles. When it entered the much harder hornblende schist west of Weaverville, it contracted very rapidly to less than one mile. I do not see how we can get around this evidence that this is a simple valley of erosion, and not a depression resulting from the sinking of a fault block.

The other hypothesis has an objection also. It is another unusual feature of these Neocene valleys that they had few tributaries. Probably the small streams came down from the uplands in short cañons with steep gradients. Pleistocene erosion, in developing the gulches, has largely obscured these earlier ravines. Outside of the Sierra Costa range it was a region not unlike that of the Sierra Nevada today, with the smaller streams flowing in shallow valleys on the uplands, and only the trunk streams in deep cañons. The topography seems to have been young, so far as that particular cycle of erosion was concerned. Naturally we would suppose that all the streams were flowing far above a baselevel of erosion, but in the flat bottoms of the old valleys and their width of nowhere much less than a mile and in places as much as four miles, we seem to have evidence that the trunk streams at least were approaching a baselevel of erosion. I will acknowledge that there is something apparently contradictory and unnatural about this, and I am unable to give a satisfactory explanation of it. However, if the Neocene valleys are the product of erosion, the fact remains that some deep cañons were excavated beneath the general level of the country. The evidence seems to me to indicate a sharp uplift of most if not all of the Klamath region in the Neocene, preceding the accumulation of the old channel deposits. The elevation may have had a maximum of several thousand feet in Trinity county and probably died out to zero on the borders of the Klamath province.

Following this elevation there seems to have been a slow

subsidence of the same area, to enable the old channel deposits to accumulate to such great thickness in the wide cañons of the trunk streams. It is only in the Trinity valley deposit that a great thickness is seen, but there are no reasons for believing that similar accumulations were not made in the other valleys. The preservation of the deposit in Trinity valley has been especially favored because the main stream abandoned the valley, which was not the case in the other valleys. It is probable that all the Neocene valleys were filled with alluvial deposits up to a certain baselevel plane and since largely reopened by erosion, a history which Lawson has shown to be duplicated in the Salinas valley in the southern Coast Ranges.[1]

If we will take our stand on the summit of the low mountain range just west of the Trinity river at Bragdon, we will get a fair idea of the condition of the surface at the close of deposition of the old channel deposit. We overlook the Neocene basin for miles to the northward and southward. We see that two limited areas apparently represent the original surface of the alluvial deposit. Some miles to the southward the summit of Buckeye Mountain appears, where it is composed of the river gravel, as a ridge with perfectly even crest-line, but sloping toward the east-southeast at a regular and low angle, estimated at about one hundred feet per mile. The altitude is 3,800 feet.

A little north of west from us, and distant only a few miles, another apparent remnant of the original surface forms a sort of plateau, only very slightly trenched by erosion, and known as the Greenhorn Flats. The elevation is about the same as Buckeye Mountain, and there is a distinct slope toward the east-southeast at a regular rate of about the same degree as the other remnant. The conviction is forced on the observer that the entire deposit north of Weaverville has been tilted toward the east-southeast at the rate of about one hundred feet per mile, and the suspicion is raised that this tilting was so rapid that the Trinity River could not maintain its old course by down-cutting

[1] *Bulletin of the Department of Geology, University of California*, Vol. I, p. 154.

into the gravel, but was forced on to the metamorphic rocks to the eastward, and so came to trench its new valley.

If we will project the reconstructed surface of the gravel deposit toward the east, we will find that it about intersects the general summit level of the ridge of metamorphic rocks between the old and the new courses of Trinity River. Beyond the new valley we will find no elevation prominently reaching above this plane until we get well up toward the summit of Trinity Mountain. As there is no evidence of faulting since the accumulation of the Neocene gravels, it is evident that at the completion of the river deposit, when its surface had reached that now represented by Buckeye Mountain and the Greenhorn Flats, the alluvial plain was bordered on the east by a low, flat belt of country, five and perhaps in places ten miles wide, a local baselevel of erosion. It is not certain that this was a perfect flat all over; indeed, it is probable that it was a series of broad valleys in which flowed the tributary streams, separated by low, smooth, in places indistinct, divides.

Certainly, the country for some miles east of the old channel was low enough to enable Trinity River to rapidly migrate across it until it had reached a distance of three to seven miles from the old course, when the vertical component of the uplift became the controlling factor, and the river simply stopped migrating and cut down into the underlying metamorphic rocks.

It is presumed that the uplift of the Klamath region was general throughout the province, but the amplitude varied. The country was bowed up into one or more great arches without faulting, except possibly on the northeastern and southwestern borders of the mountain system. From the group of high mountains west of the old Trinity valley to the present Sacramento valley near Redding, I regard as the eastward slope of one of these great arches. Between Redding and Shasta there are traces of an old peneplain[1] earlier in age than that on which the Red Bluff gravels lie, and this I would correlate with the late Neocene baselevel developed on the east border of

[1] JOUR. GEOL., Vol. II, pp. 34, 35.

Trinity valley. The former rises from six hundred to about one thousand feet above the sea in less than three miles. Projecting this plain westward and the tilted baselevel of Trinity valley eastward until they intersect, we would find that nearly all of the gulches lie below this level, while the mountain tops which reach above it have a more subdued and older-appearing topography.

Completed baseleveling was only effected on narrow strips on the border of the Sacramento valley and on the east border of the Trinity valley. The country between was quite undulating, and contained rounded mountains reaching elevations of 1,000 and even 2,000 feet above the neighboring baselevel. These residuals were of the same category as those in the McCloud-Pit projection of the Klamath mountains, which may be shown to rise as monadnocks above an uplifted baselevel, represented by Bagley Flat.

At the Big Bend of Pit River and along Kosk Creek, a northern tributary, the Ione sandstone, as identified by Diller[1] is strongly developed, having a probable thickness of about six hundred feet. It dips easterly at a low angle, and passes under the lavas of the Lassen volcanic range. On the west, the surface of the metamorphic rocks of the Klamath region, here chiefly Jurassic in age, come out from under it and rise to the westward at about the same angle as the eastward dip of the sandstone. The Ione pebbles are scattered over this slope to a distance of several miles from the present Ione escarpment. This slope represents the pre-Ione surface of the Klamath region, and consequently is not the equivalent of the latest stage of the Sierra Nevada peneplain.

On the north side of Pit River, west of Cañon Creek, there is a high terrace known as Bagley Flat. It is a shelf cut into the slope of the Klamath mountains. Its present altitude is about 2,750 feet, or 1,200 feet above Pit River. It corresponds in height with the lava plain on the south of the river, but instead of being a constructional plain of sandstone overlaid by andesite, it is a baselevel of erosion. The Neocene lava occurs as rem-

[1] Lassen Peak Folio of the *Geologic Atlas of the United States.*

nants on this shelf, fixing its age as that of the andesite eruption. I regard it as a sort of coastal plain of erosion, baseleveled by the body of water in which the Ione sandstone was deposited. After the Ione formation was completed, the andesitic lava flowed over the sandstone area and lapped over on to this narrow coastal plain. This andesite, from its lithologic character and from its relations to the underlying Ione formation and an overlying basalt, may be correlated with the andesitic tuffs and lavas partly burying the Sierra Nevada peneplain. Hence, Bagley Flat is the equivalent of the Middle Pliocene peneplain of the Sierra Nevada region.

Back of Bagley Flat, two mountains, Bagley Mountain and another unnamed, rise rather steeply to altitudes respectively of 4,437 and 3,905 feet, and were monadnocked on the baselevel of the Middle Pliocene to the extent approximately of 1,600 and 1,100 feet. West from here, as far as the Sacramento River, the Klamath mountains consist of a group of peaks, of which these two mountains are members. While the general surface slopes to the south and the peaks reach altitudes of 4,000 to over 6,000 feet, there is not sufficient uniformity in their height to suggest a dissected peneplain. These peaks have the aspect rather of monadnocks, and the relation of several of them to Bagley Flat shows that they belong to the same category as the monadnocks of the Sierra Nevada region. This portion of the Klamath region was nearly all residual, baseleveling only being effected on a narrow strip around the head of the Sacramento valley. It is a significant fact that the Klamath mountains rise much more abruptly on the side of the great valley than do the Sierra Nevada Mountains. This is beautifully exemplified by a view toward the north from Redding, where Bear Mountain and other peaks in the vicinity appear to rise sharply from the plain.

A view toward the southeast from Brock Mountain shows a number of flat-topped ridges bearing a marked resemblance to eastern dissected peneplains, but this is quite local, and I do not know its significance. If any older peneplain than the Middle

Pliocene of the Sierra Nevada region was developed in this region, it has been completely destroyed by erosion, and is not identifiable, while, as already intimated, the Middle Pliocene baselevel did not penetrate far from the border of the present Sacramento valley. In general, we may say, the present topographic features are older than those which dominate the Sierra Nevada country.

The nearest approach to the development of a late Neocene peneplain in Trinity county was effected at the close of deposition of the Neocene gravels. The surface of the alluvial deposits rose by aggradation and the neighboring rock surface sank by degradation, until at the close of the epoch the two planes met. This is precisely the same relation that exists between the auriferous gravels and the peneplain of the Sierra Nevada region, indicating that we are treating equivalent and contemporaneous events. So confident am I that this is true that I am inclined strongly to accept the Neocene baselevel of the region under discussion as a datum plane of the same value as the Sierra Nevada peneplain, consider its maximum development of rather late Pliocene age, and base upon it speculations as to the ages of all other physiographic features in the province.

The Sierra Costa Mountains rose above the Neocene baselevel to elevations of three to five thousand feet, and had a topography similar in its larger features to that of today. The higher valleys of these mountains are essentially the valleys of the Neocene. They are commonly called "cañons" by the miners, because they have relatively broad floors and very steep walls. Part of this cañon-like form is due to glaciation, but more is preglacial in its origin. The work of the glaciers was short and confined to a removal of talus from the foot of the precipices, to the smoothing of inequalities, and to the filling of the deeper portions of the valleys by drift débris.[1] Beyond the ends of the glacier sites, the same broad valleys continue at the same level, but this fact is obscured by the Pleistocene erosion of deep gulches in the bottoms of the older valleys, the slopes of which

[1] JOUR. GEOL., Vol. VII, 1899.

later system of valleys often coalesce with the slopes of the older valleys so as to make the whole trench, perhaps five thousand feet in depth, appear as the work of a single cycle of erosion. Usually, however, there is a shoulder high up on the slopes which is not always explained by the structure or by landslides, and the concurrence of a series of these shoulders at about the same elevation on both sides of one of these valleys raises the suspicion that they represent the bottom of the Neocene valley.

So far as is now known the Sierra Costa range is the only portion of the Klamath region or indeed of any part of northern California which possessed a rugged, sierra-like topography during the late Neocene, and it should be awarded the distinction of being the oldest prominent mountain range within the state, unless such exist south of the Tehachapai range.

Correlation.— Rhyolite tuff has been found by Diller in the Indian Creek basin, and I believe also in Hyampour valley, and by Anderson and the writer in Hay Fork valley. The first investigator thought the material had been showered over the hills as fine ashes and then carried down into the streams, and thus became interstratified with the alluvial gravels. It was largely because of the presence of this tuff that he provisionally correlated the Neocene gravels in Trinity county with the Ione formation. At the same time he recognized the possibility that the tuff may have been derived from the group of volcanoes in the Coast Range region, in Lake county, and may not belong to the epoch of rhyolitic extrusions in the Sierra Nevada region.

The latter represent a distinct epoch of the period of vulcanism, and this rhyolite epoch was contemporaneous with the accumulation of the auriferous gravels proper or high-level channels. The latter are now thought to be the chronologic equivalent of the San Pablo formation, presumably of Lower Pliocene age. If the rhyolite tuff of the Klamath region was derived from the Sierra Nevada or Lassen Peak volcanoes, it would imply that the tuff-bearing portion of the Neocene gravels is probably Lower Pliocene in age. The presence of lignite in

the Hay Fork and Hyampour valleys also favors this correlation, for lignite is very characteristic of the Ione formation, another supposed equivalent of the San Pablo formation.

However, it seems to the present writer more probable that the rhyolite tuff was derived from the Lake county volcanoes. There is a great mass of tuff in the upper end of the great valley, extending west of the Sacramento River, and clearly referable to the Lassen Peak volcanic range as a source, but it is andesitic in character. None of this reached the Trinity county basins so far as I am aware. The occurrence of the rhyolite tuff in the southern part of Trinity county alone seems to imply that it was showered from the south and not from the east. Strong winds come oftener from the direction of Lake county than from that of the Lassen Peak range.

I am informed that the volcanic series of Lake county is essentially Middle Pliocene in age, being apparently the equivalent of the Berkeleyan series. About the close of deposition of the San Pablo sandstone, rhyolitic ashes seem to have been widely showered over the northern Coast Range region, and it is probable that at this time similar material reached the Trinity county basins.

Whether we refer the source of the tuff to the Sierra Nevada Lassen Peak or to the Lake county volcanoes, we arrive at virtually the same result in the matter of the probable age of the tuff-bearing portion of the Neocene gravels of the Klamath region, namely, about the time of transition from the Lower to the Middle Pliocene.

The lignite and tuff are found near the rock-floor of the old Neocene valleys, and simply tentatively fix the age of the lower portion of the gravel series. The accumulation of the gravel continued until the inception of the profound orographic disturbance to which the Pleistocene valleys are due. In a separate paper it is hoped to show that the latter are equivalent to the Sierran valleys of the Sierra Nevada province, and that the orographic disturbance referred to in this paragraph was that which terminated the Pliocene and inaugurated typical Quater-

nary conditions in California. It is, therefore, reasonably certain that the upper portion of the Neocene gravels of the Klamath region represents the Upper Pliocene. In short, the alluvial filling of the Neocene valleys is probably the chronologic equivalent of the whole of the Coast Range Pliocene series, with its San Pablo, Berkeleyan, and Merced divisions.

I have correlated in a general way the Neocene baselevel of the Trinity valley with the peneplain of the Sierra Nevada region, but this requires some qualifications. The latter was developed in early Pliocene time and largely buried under andesite lava and tuff during the Middle Pliocene time. Then it was slightly disturbed and partly resurrected by erosion during late Pliocene time. In the Klamath region there were deep cañons in the earlier portion of the Pliocene period, and the Neocene baselevel reached its stage of maximum development at about the close of the period. Then came the great uplift which terminated low-level conditions in both provinces.

OSCAR H. HERSHEY.

BERKELEY, CALIF.,
February 7, 1902.

NOTE ON THE CARBONIFEROUS OF THE SANGRE DE CRISTO RANGE, COLORADO.

THE detailed section given below was taken at the crest of Sangre de Cristo range, directly west of Trinidad, Colo., between the sources of the Middle Fork and the North Fork of the Purgatory River. The Sangre de Cristo range reaches a maximum elevation in this region of 14,079 feet, in Mt. Culebra. From this peak northward the crest of the range descends gradually to an elevation of about 9,300 feet at Veta Pass, thence rises again to Sierra Blanca — 14,413 feet — the highest peak in Colorado.

The crest of the Sangre de Cristo range is composed for the most part of coarsely crystalline rock flanked by sedimentaries. At the point where the section was taken the crystallines of the crest pass gradually beneath the surface, giving place to the sedimentary formations. From this point northward for a considerable distance the crest of the range is composed mainly of strata having a northeastward dip (see Hayden's *Atlas of Colorado*). Mr. Endlich maps a considerable portion of the sediments as Lower Carboniferous; but the greater part, including the barren red sandstones, which are several thousand feet thick in this region, is mapped as Upper Carboniferous. The red sandstones are obviously a part of the Red Beds, whose wide distribution in the mountain region is well known, but whose age is still a matter of doubt.

It was in the hope that some light might be thrown upon the age of certain isolated remnants along the eastern slope of the mountains that I took the trip to the fossil-bearing series at the crest of the range. In place of the Lower Carboniferous series which I had expected, I found the Upper Carboniferous series reported in the accompanying section. This section was taken in a cañon near the southern limit of what Mr. Endlich mapped as Lower Carboniferous. To the north of this point

the series attains a somewhat notable thickness, due mainly to the presence of strata younger than those represented in the section. Nearly all the layers of the section are more or less fossiliferous, but the most productive horizons are about 150 feet from the base. The 28-foot shale yielded thirty species. Some of these species were found at each of the horizons collected from. The lower 100 feet yielded few fossils, but none were found which could be referred to the Lower Carboniferous.

My collections were submitted to Dr. Stuart Weller, who very kindly identified the species for me and furnished the following lists: Zaphrentis sp. undet., Orbiculoidea convexa Shum., Orbiculoidea missouriensis Shum., Chonetes mesoloba N. & D., Productus longispinus Sow., Productus costatus Sow., Productus cora D'Orb., Spirifer cameratus Morton, Spirifer rockymontana Marcou., Reticularia perplexa McCh., Seminula argentea Shep., Aviculopecten carboniferus Stev., Astartella concentrica McCh., Nucula ventricosa H., Nuculana bellistriata Stev., Pelecypod (genera and sp. undet.), Bellerophon percarinatus Con., Bellerophon carbonarius Cox., Bellerophon montfortianus N. & P., Bellerophon sp. undet., Rotella verrucelifera White, Soleniscus brevis White, Soleniscus sp. undet., Sphaerodoma texana Shum., Sphaerodoma sp. undet., Trachydomia wheeleri Swall. var., Naticopsis altonensis McCh., Naticopsis altonensis var. gigantea M. & W., Pleurotomaria perizomata White, Pleurotomaria (several small species undet.), Murchisonia copei White, Orthoceras sp. undet., Syringopora sp., Campophyllum torquium Owen, Straparolus catilloides Con.

A few fossils were found as loose fragments and their horizons not determined. They are as follows: Derbya crassa M. & H., Hustedia mormoni Marcou., Allorisina subcuneata M. & H., Schizodus wheeleri Swall., Bellerophon (large sp. undet.), Temnocheilus winslowi M. & W., Phillipsia sp., large fish spine.

A small collection was also obtained from the western slope of Veta Pass, five miles above Placer. The section here is composed of sandstones, limestones, shales, and conglomerates simi-

lar to the section north of Mt. Culebra. The following species were found: Zaphrentis sp., Orbiculoidea sp., Derbya crassa M. & H., Chonetes granulifera Owen, Chonetes mesoloba N. & P., Productus nebrascensis Owen, Productus costatus Sow, Spirifer cameratus Morton, Reticularia perplexa McCh., Seminula argentea Shep., Hustedia mormoni Marcou, Aviculopecten occidentalis, Astartella concentrica McCh., Schizodus Wheeleri, Swall., Bellerophon percarinatus Con., Bellerophon inspeciosus White? Soleniscus sp., Conularia? sp., Orthoceras sp.

SECTION TAKEN AT THE CREST OF THE SANGRE DE CRISTO RANGE, BETWEEN MIDDLE FORK AND NORTH FORK OF THE PURGATORY RIVER.

FEET.	
10	Hard quartzitic conglomerate.
5	Dark shale.
2	Limestone, fossiliferous.
12	Red sandstone, with bands of red shale and irregular masses of limestone.
4	Greenish argillaceous sandstone.
18	Pink sandstone, argillaceous above, conglomeratic below.
4	Fossiliferous limestone.
10	Deep red sandsone, conglomeratic at the base, shaly near the top.
20	Limestone, arenaceous near the base.
13	Massive, light-colored grit, coarse and conglomeratic.
6	Banded sandstone and limestone intimately commingled. The limestone is often in more or less rounded masses. Irregular beds of gravel occur in places.
3	Nodular limestone.
8	Massive limestone.
3	Shale with limestone nodules.
23	Massive limestone.
20	Coarse sandstone, conglomeratic in the lower half.
8	Massive grit (local unconformity).
10	Calcareous shale, passing to black shale, with limestone nodules near the top.
15	Fossiliferous limestone with sandstone layers. Cup corals abundant.
6	Massive limestone.
8	Shale.
2	Coarse grit.
10	Sandstone with large nodules and irregular masses of limestone.
25	Shale with bands of sandstone and limestone.
4 to 12	Banded limestone.
28	Soft black shale, fossiliferous.
9	Coarse grit.
6	Black shale.
2 to 20	Coarse grit, conglomeratic in places.

45	Dark shale, with limestone nodules and thin seams of sandstone; runs to massive limestone in places; becomes red and arenaceous near the base.
7	Coarse grit.
10	Dark red shale, with nodules and irregular masses of limestone.
4	Limestone.
12	Red to black micaceous shale, with bands of sandstone near the base, and limestone nodules near the top.
10	Coarse grit.
?	Red grit and conglomerate.
	Crystalline rocks of the mountains.

WILLIS T. LEE.

TRINIDAD, COLO.

GLACIAL PHENOMENA IN THE ADIRONDACKS AND CHAMPLAIN VALLEY.

INTRODUCTION.

THIS paper was undertaken at the suggestion of Professor J. F. Kemp, of Columbia University, to whom the writer is indebted for much valuable assistance. The data on striæ were gathered from all possible sources — from the published reports of the New York state museum, from the field notes of Professor Kemp,[1] from the notes of Professor Cushing in the north and west, and from those of the writer in the south. Especial thanks are due to Dr. Cushing for the information thus furnished. The study of the Pleistocene history of the Adirondacks has been fragmentary, and will be subject to much elaboration in the future. The purpose of the present paper is the correlation of such facts as are known from the writer's observation and from the work of others, and the interpretation of these facts in their bearing on the erosion history of the region. Especial thanks are also due to Professor Kemp for assistance with the map.

TOPOGRAPHIC RELATIONS OF THE ADIRONDACK REGION.

The Adirondacks form the most conspicuous topographic feature of northern New York. Within this area of about ten thousand square miles are some dozen peaks which rise to altitudes of approximately five thousand feet. The valleys between these highest mountains are deep and narrow, their bottoms being about two thousand feet above the sea. This central mass of high peaks is composed entirely of anorthosite; surrounding it are lower gneissic peaks of two to three thousand feet in altitude, with gentler outlines and broader intervening valleys. Towards the southwest this gneissic area stretches for some miles as a plateau, with undulations caused by old valleys, now largely drift-filled. Surrounding this crystalline area is a plain cut on

[1] Used by permission of the director of the United States Geological Survey.

gently dipping Palæozoic rocks and sloping eastward to Lake Champlain, northward to the St. Lawrence, westward to Lake Ontario, and southward to the Mohawk. The central peaks, of which Marcy is the highest, lie about thirty miles west of Lake Champlain and one hundred miles south of the St. Lawrence.

GLACIAL PHENOMENA.

General relations of the region to the direction of ice movement.— The region lies 250 miles north of the terminal moraine on Long Island, and is thus well within the limits of the last continental ice sheet. It is interesting to determine the effect upon the direction of ice movement of this enormous mass of rock across its path, and what effect the ice left upon the region thus traversed. As is well known, the ice in the last glacial epoch was differentiated into lobes which conformed more or less closely to pre-existing valleys.[1] One such lobe lay in the Hudson and Champlain valleys, its axis in the southern part corresponding, not to the Hudson valley, but to the broad valley west of the Palisade Ridge.[2] Another lobe lay to the westward, presenting a fringed margin in the shape of local glaciers in the Finger Lake region, its upper portion coming in a broad stream from the upper St. Lawrence valley. These two valleys intersect slightly northeast of the Adirondacks. The prevailing direction in the St. Lawrence valley being southwest, it follows that these two streams must have separated near the point of junction of the two valleys.[3]

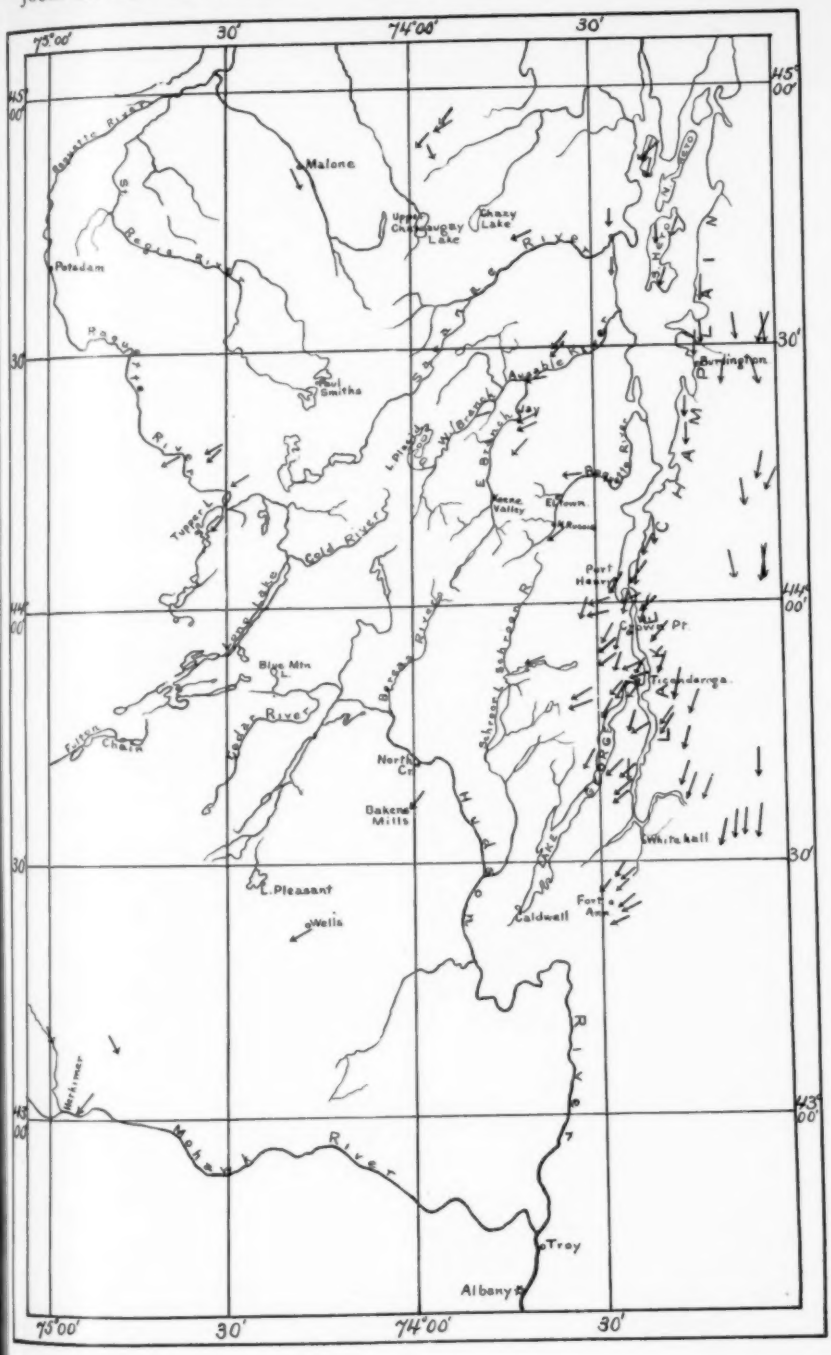
The dispersion of ice from northern Canada seems to have taken place from several centers.[4] Eastern Labrador was one such center, ice moving out from it in all directions. Glacier ice seems to show a general tendency to choose broad, open valleys

[1] T. C. CHAMBELIN, "Preliminary paper on the Terminal Moraine of the Second Glacial Epoch." *Third Annual Report U. S. Geol. Surv.*, pp. 295–402.

[2] R. D. SALISBURY, "Drift Phenomena of the Palisade Ridge," *Annual Report Geol. Surv. of New Jersey, 1893*, pp. 157–225.

[3] For summary of literature on Canada see SIR J. WILLIAM DAWSON, *The Canadian Ice Age*, Montreal, 1893.

[4] R. BELL, "Glacial Phenomena in Canada," *Bull. Geol. Soc. Amer.*, Vol. I, 1890.


75°00'
30'
74°00'
30'
45° 00'
30'
44° 00'
30'
43° 00'
30'
Malone
Potsdam
Raquette River
Racquette River
Upper Chateaugay Lake
Chateaugay Lake
Chateaugay River
Saranac River
Au Sable River
Burlington
Paul Smiths
Lake Placid
Keene Valley
Elizabethtown
Port Henry
Cold River
Tupper Lake
Blue Mtn.
Cedar River
Bacon Brook
Schroon River
Ticonderoga
Fort Ann
North Creek
Bakers Mills
Hudson River
Whitehall
L. Pleasant
Wells
Caldwell
Fort Ann
Herkimer
Mohawk River
Troy
Albany
ADIRONDACK MOUNTAINS

for its progress, and to become stagnant in narrow passes.[1] The St. Lawrence valley was therefore a natural channel for ice moving from Labrador, and in the same way at the junction of the St. Lawrence and Champlain valleys two broad outlets of easy progress were afforded. The Adirondack highlands, with their steep-sided, narrow passes were most unfavorable to glacier motion.

STRIÆ AND GENERAL NATURE OF ADIRONDACK ICE MOVEMENT.

Striæ in the Champlain valley are somewhat variable in direction. The prevailing direction is southwest, but cross striæ are found, and southeast directions are not uncommon. This is what might be expected on the hypothesis that the Adirondacks were filled with nearly stagnant ice. The ice stream coming down the St. Lawrence would be forced either to turn aside to the south or to push on in its own direction against a great immovable mass. The northern part of the Champlain valley would therefore be a critical point, and slight variations in the amount of ice, or in temperature, or other variable factors, might make great differences in the direction of motion.

Upon the crystalline rocks of the Adirondacks proper the direction is uniformly southwest. No striæ were observed in this region in other directions, except those which could be clearly shown to be influenced by some topographic variation of local character. There appears to be no change in direction with altitude. The approach to the high and rugged mountains is marked by a conspicuous decrease in the number of striæ, which is what would be expected if the ice were stagnant in the valleys. Chamberlin observes that ice movements as a rule are from the basins to the highlands, due to the increase in relative rate of waste with the retardation of the ice mass. In the Adirondacks this appears to have had but slight expression; such data as are available indicate that ice which had once passed the critical point at the boundary of the region, passed on toward

[1] T. C. CHAMBERLIN, "Rock Scorings of the Great Ice Invasion," *Seventh Annual Report, U. S. Geol. Surv.*, 1885–86, pp. 155–248.

the southwest without very great deflection. The bottoms of the deeper valleys in the interior not only show no striæ, but very little smoothing and polishing, while preglacial fault cliffs stand out perfectly sharply, with scarcely a sign of corrasion. The summits however have been markedly smoothed; the abundant bowlders of Potsdam sandstone on even the highest peaks give unquestionable evidence that the region was entirely buried, and by ice in vigorous motion. The conclusion reached is, therefore, that the ice entered the region from the northeast, flowing on in that direction where open valleys afforded opportunity, becoming stagnant in narrow valleys, and finally at the time of its greatest advance burying the region entirely, an upper southwestward moving current passing over the stagnant valley masses below.

The accompanying table enumerates all the striæ that have been accurately recorded from the region. In the literature there are many references of an indefinite nature, speaking of striæ in general northeasterly directions. These were of necessity omitted from the table and map, but the references to them indicate that striæ are more numerous than is shown on the map. Not a single record has been found among the highest mountains. The map shows the three zones of striation: a zone along the Champlain valley where striæ are very numerous and variable in direction; a zone along the gneissic hills where they are less numerous and prevailingly northeast; and a zone among the high anorthosite peaks, where striæ are entirely lacking, though the mountain tops here are conspicuously smooth. The readings taken by Professor Kemp along Lake Champlain and Lake George are so numerous that they could not all be put upon the map, hence the contrast is even more striking than it appears. Farther north along Lake Champlain striæ appear to be as numerous as in the southern region, but accurate records have not been taken in many localities. All readings are referred to the true north; each striation is credited to its observer in the right hand column of the table. In Vermont and the Islands in Lake Champlain the striæ on the map are taken from Hitchcock.[1]

[1] *Geology of Vermont*, Vol. I.

TABLE OF STRIÆ IN THE ADIRONDACKS.

CLINTON COUNTY.

Direction (referred to the true north).	Township.	Locality.	Feet A. T.	Formation.	Remarks.
S. 35 W.	Ellenburgh	Northwest corner, near Franklin county	.....	Potsdam	H. P. C.
S.	"	Ditto, and near Clinton township line	.....	Gneiss	"
S. 45 W.	"	6 miles east of last	.....	Potsdam	"
S. 10 E.	"	2 miles south-southeast from first	.....	"	"
S. 20 W.	"	1 mile northeast from third	.....	"	"
S. 35 E.	Clinton	1 mile east of Churubusco	.....	"	"
S.	"	3 miles northeast of last	.....	"	"
S. 30 W.	Ausable	3 miles north of Clintonville	.....	"	"
S. 40 W.	"	2 miles north of last, near Peru township line	.....	"	"
S. 55 W.	Saranac	5 miles south, and 1 mile east from Dannemora village	.....	"	"
S. 5 E.	Plattsburg	On Bluff Point, ¼ mile west of Hotel Champlain	.....	Chazy	"
S.	"	2½ miles north of Plattsburgh, near Beekmantown line	.....	"	"
N. 15 E. } N. 15 W. }	Dannemora	On shore of Chateaugay Lake	.....	Potsdam	"

FRANKLIN COUNTY.

N. 20 E.	Malone	4 miles southwest of Malone	.....	Gneiss	H. P. C.
S.	"	8 miles south of Malone (At Branch pond outlet)	.....	Augite } Syenite }	"

ESSEX COUNTY.

N. 92 E.	Jay	Near Ausable Forks	.....	Gneiss	J. F. K.
N. 52 E.	"	Lower Jay	.....	Anorthosite	"
N. 52 E.	"	2 miles east of last	.....	"	"
N. 12 E.	"	Southeast of Upper Jay	.....	.....	"
N. 28 E.	Crown Point	West of Crown Point village	200	Gneiss	"
N. 12 E.	"	West of Crown Point village	.....	"	I. H. O.
N. 38 E.	"	Near Lake Champlain, 1 mile north of Burdick's Crossing	100	Calciferous	J. F. K.
N. 42 E. } N. 47 E. }	"	Burdick's Crossing	150	"	"
N. 12 E. } N. 62 E. }	"	Coot Hill	1,100	Granite } Gneiss }	"
N. 49 E.	"	Sugar Hill	400	Gray Gneiss	"

ESSEX COUNTY.—*Continued.*

Direction (referred to the true north).	Township.	Locality.	Feet A. T.	Formation.	Remarks.
N. 47 E. } N. 27 E. }	Crown Point	Breed's Hill	300	Calciferous	J. F. K.
N. 57 E.	"	South of Towner Pond	600	GabbroGn's	I. H. O.
N. 50 E.	"	South of Towner Pond	1,200	Pegmatite	"
N. 62 E. } N. 32 E. }	Ticonderoga	3 miles east of Street Road	200	Calciferous	J. F. K.
N. 57 E.	"	½ mile south of last	200	"	"
N. 44 E. } N. 22 E. }	"	½ mile south of last	*		"
N. 57 E.	"	2 miles north of Addison Junction	200		"
N. 52 E.	"	Addison Junction	150	Calciferous	"
N. 52 E. } N. 27 E. }	"	Ticonderoga village near outlet of Lake George	200	Syenite	"
N. 52 E.	"	½ mile south	200	Sed. Gneiss	"
N. 47 E.	"	Mt. Hope	300	Calciferous	"
N. 67 E.	"	Northeast of Delano	200	Pegmatite	"
N. 37 E.	"	Delano	100	Calciferous	"
N. 42 E.	"	1 mile west of Cook's Mountain	300		"
N. 47 E.	"	½ mile southwest of last	400		"
N. 32 E.	"	½ mile south of last	500		"
N. 25 E.	"	In Ticonderoga village, north of river	200	Syenite	"
N. 22 E.	"	½ mile southwest of last	200		"
N. 42 E.	"	North of Ticonderoga ruin	150	Potsdam	"
N. 62 E.	"	½ mile east of last	120		"
N. 47 E.	"	1 mile northeast of Baldwin	350	Potsdam	"
N. 30 E.	Hague	Point south of Friend's Point	340	Gneiss	"
N. 62 E.	Wilmington	West of Ausable River, 3 miles southwest of Wilmington village	1,300		"
N. 72 E.	Lewis	Near town of Lewis	650		"
N. 70 E.	Moriah	3 miles south of Moriah village	1,000	Gneiss	"
N. 65 E.	"	½ mile south of last	1,100	"	"
N. 70 E.	"	4 miles south of Moriah village	1,100	"	I. H. O.
N. 52 E.	Elizabethtown	1 mile southwest of New Russia, on the Boquet	680		J. F. K.
N. 70 E.	Schroon	North shore of Paradox Lake	820	Gneiss	I. H. O.

*Scratches faulted by crack N. 30 E.

HERKIMER COUNTY.

S. 30 E.		1 mile north of Salisbury Centre		* Gneiss	H. P. C.
S. 10 E.		2½ miles north, a little west of Middleville		Trenton	"
S. 30 W.		2 miles south and 1 mile west of Little Falls		Birdseye	"

*Of Grenville series.

ST. LAWRENCE COUNTY.

Direction (referred to the true north).	Township.	Locality.	Feet A. T.	Formation.	Remarks.
S. 45 W.	.....	N. Y. C. & H. R. railroad cut, 2½ miles north of Horse Shoe station.....	.....	{ Augite Syenite	H. P. C.
S. 40 W.	.....	Railroad cut 1½ miles north of Horse Shoe.....	.....	{ Augite Syenite	"
N. 80 W.	.....	Railroad cut ½ mile east of Childwold.....	.....	Gneiss *	"
N. 75 W.	.....	Railroad cut ½ mile south of Childwold.....	.....	{ Augite * Syenite	"
S. 30 W.	.....	East shore of Big Tupper..	.....	{ Augite † Syenite	"

*These two readings are apparently of basal motion, influenced by the Raquette valley and the mass of Arab Mountain to the south, the ice moving west around it.

†Four different readings.

WARREN COUNTY.

N. 20 E.	Johnsburg	3 miles east of Baker's Mills	.....	Gneiss	J. F. K.

WASHINGTON COUNTY.

N. 62 E.	Putnam	2 miles east of Lake George, opposite Hague.....	500	Potsdam	J. F. K.
N. 52 E.	"	½ mile east and slightly north of last.....	600	"	"
N. 52 E.	"	1 mile south of last.....	600	"	"
N. 67 E.	"	1 mile west of Putnam station	.....	Calciferous	"
N. 47 E.	Dresden	Bluff Head.....	400	Gneiss	"
N. 37 E. / N. 27 E. \	"	2 miles west of last.....	1,100	"	"*
N. 32 E.	"	½ mile southwest of last (on Spruce Mountain).....	1,200	Gabbro	"
N. 62 E.	"	2 miles east of last (near Lake Champlain).....	200	Gneiss	"
N. 42 E.	"	East side of Spruce Mountain.....	1,400	"	"
N. 37 E.	"	½ mile east of last	1,150	"	"
N. 42 E.	"	1 mile north of Dresden Centre	500	"	"
N. 42 E.	"	½ mile north of Dresden Centre.....	450	Syenite	"
N. 52 E.	"	1 mile west of Dresden Centre.....	1,100	.....	"

*Crossing striæ.

WASHINGTON COUNTY.—*Continued.*

Direction (referred to the true north).	Township.	Locality.	Feet A. T.	Formation.	Remarks.
N. 42 E.	Dresden	Dresden Centre.....	500	Gneiss	J. F. K.
N. 37 E.	"	½ mile south of last.....	500	"	"
N. 32 E.	"	1 mile slightly south of east of last (near Lake Champlain).....	100	"	"
N. 32 E.	"	½ mile south of last.....	100	"	"
N. 37 E.	"	East of Long Pond.....	1,000	Potsdam	"
N. 45 E.	Fort Ann	.....	.....	.....	"
N. 40 E.	"	.....	.....	.....	"
N. 28 E.	"	.....	.....	.....	"
N. 55 E.	"	.....	.....	.....	"
N. 50 E.	"	.....	.....	.....	"
N. 60 E.	"	.....	.....	.....	"
N. 55 E.	"	.....	.....	.....	"

The widest valleys, and hence the most favorable for ice movement, were the Champlain and St. Lawrence valleys bounding the region. Therefore, as the ice advanced down the lower St. Lawrence, it must have split into two streams on either side of the Adirondacks; at the time of its maximum extent these two streams flowed around the obstruction, their edges meeting in the Mohawk valley near Utica; as it retreated the valley portions melted first, forming lakes in the depressions, while local glaciers were left on the highest mountains.

These results are entirely in accordance with the phenomena to be found in the Mohawk valley.[1] Later work completely bears out the early suggestion of Chamberlin, in the report already cited.[2] After discussing the moraines of the Mohawk valley he says:

> I hesitate at this stage of the inquiry to encourage any confident opinion in regard to the exact history of glacial movements in the Mohawk valley, further than the general presumption that massive currents having their ulterior channels in the Champlain valley on the one hand, and in the St. Lawrence on the other, swept around the Adirondacks and entered the

[1] ALBERT PERRY BRIGHAM, "Topography and Glacial Deposits of Mohawk Valley," *Bull. Geol. Soc. of America*, Vol. IX, pp. 183-210.

[2] T. C. CHAMBERLIN, *Third Annual Report, U. S. Geol. Surv.*, pp. 295-402.

Mohawk valley at either extremity, while a feebler current, at the height of glaciation, probably passed over the Adirondacks and gave to the whole a southerly trend.

The detailed work of Brigham has already proved the accuracy of this general statement for the Mohawk valley. The data gathered for the present paper tend to show its truth as regards the Adirondack area.

GLACIAL DEPOSITS.

The glacial deposits of the Adirondacks belong to the time of retreat and melting of the ice. Very little true morainal material is found, whereas stratified drift is abundant. The reason for this condition is evident; during the time of maximum advance of the ice the Adirondacks were so far from the border as to be within the area where movement was too vigorous for deposition; such deposits as there are belong to the time when the melting ice afforded opportunity for the deposition of its drift in bodies of water. Lake Champlain is the shrunken remnant of a large body of water[1] which occupied the depression, while ice still stood in the St. Lawrence valley. Shore deposits were laid down along the border of this lake, while mud was laid down farther out in its waters. Large deltas were formed at the mouths of the streams. With the further retreat of the ice to the north, the waters of this lake subsided, and the shore deposits and deltas were formed farther and farther out, successively overlapping on the clays of the preceding stage.[2] During a part of this period the Champlain valley was an arm of the sea, some of the sands and clays containing marine fossils.

On the great plain to the north true morainal material is found, though sparingly. The plain is overlain by a succession of sand plains at various levels. Deltas are numerous. The complete history of these successive stages has not been attempted, nor their correlation with the Champlain deposits.

[1] "Lake Hudson-Champlain," See WARREN UPHAM, *Bull. Geol. Soc. Amer.*, Vol. III, 1891.

[2] H. P. CUSHING, "Geology of Clinton County," *Fifteenth Ann. Rept. N. Y. State Geologist.*

Overlying these sand plains local moraines are found, which appear from the character of the drift, to have been deposited by glaciers radiating from the center of the Adirondack highlands after the melting of the main body of the ice.[1]

Local moraines are also to be found in the valleys of the central part of the region. Such moraines always overlie stratified deposits and by their position and their character indicate a period of local glaciation. The cirques on the side of many of the higher mountains afford further evidence of the same phenomenon. There is no evidence of extensive local glaciation, of the nature of an ice cap such as Professor Chamberlin describes in Greenland; the moraines are too infrequent and the region too thoroughly covered by drift brought by the advancing ice from the northeast which would have been removed by extensive glaciation. The evidence points to the presence of local valley glaciers in a few isolated localities.

The closing stages of the ice invasion were marked by the presence of lakes in the larger valleys. Evidence of them is to be seen in the frequent flat valley floors of stratified drift, and the deltas opposite the mouths of tributary valleys. A remarkably fine example of such a lake is to be seen near Elizabethtown, the town itself standing on a delta terrace.[2] There are many such lake flats, which were probably contemporaneous with the Champlain submergence, existing as lakes in the interior at the time Lake Champlain was a sea bay. Many of these lakes were held up by stagnant ice, and the draining of them took place in late Champlain time when the climate was too warm for ice to remain. Others were held up by drift, and the extinction of these took place in Recent time partly from draining and partly from filling by sediment and choking by vegetation.

Terraces are to be found along some of the larger rivers,

[1] H. P. CUSHING, "Report on the Potsdam and Pre-Cambrian Boundary North of the Adirondacks," *Sixteenth Ann. Rept. N. Y. State Geologist.*

[2] H. RIES, "A Pleistocene Lake Bed at Elizabethtown, Essex Co., N. Y.," *Trans. N. Y. Acad. Sc.*, 13 (1893), p. 197.

notably the Schroon and upper Hudson. The upper terrace of the Schroon suggests an origin as a "kame terrace," deposited against the side of a mass of stagnant ice. It has been so much eroded postglacially (its removed material being often blown into dunes on the lower terrace), that its complete history will need more careful study than has yet been given.

Professor Spencer claims to have traced the Iroquois beach for some miles north of the Adirondacks,[1] his interpretation being questioned by Messrs. Gilbert[2] and Taylor.[3] No thorough work has yet been done and the northern deposits are few and scattered. The problem, therefore, of the correlation of the Pleistocene stratified deposits of the three regions — the Champlain valley, the plain north and west of the Adirondacks, and the Adirondacks proper — is quite unsolved. The question of a Pleistocene subsidence, advocated by Professor Spencer is also an open one.

EROSION HISTORY OF THE ADIRONDACKS.

Certain main lines of drainage were established before the close of Cambrian time. These are tremendously modified by later adjustments, notably from faulting and glaciation, but the Cambrian drainage can be made out and is in some localities remarkably similar to the present.[4] The Cambrian topography was mature, streams being located along the soft limestone of the Grenville series, while the harder gneisses stood out as rounded ridges. As the Adirondack island sank beneath the Ordovician sea, these mature rivers were drowned and sediments deposited along their courses. At the close of Trenton time the region was wholly submerged. No evidence of this complete submergence is forthcoming from the Adirondacks themselves,

[1] "The Iroquois Shore North of the Adirondacks," *Bull. Geol. Soc. Amer.*, Vol. III (1891), pp. 488-92.

[2] Discussion of the above by GILBERT, *op. cit.*, pp. 492-95.

[3] F. R. TAYLOR, "Lake Adirondack," *Amer. Geol.* (1897), Vol. XIX, pp. 392-96.

[4] J. F. KEMP, "Physiography of the Eastern Adirondacks in the Cambrian and Ordovician Periods," *Bull. Geol. Soc. Amer.*, Vol. VIII, 408-12.

but the homogeneous character of the deposits surrounding them, and the entire absence of any indications of shore formations or island character, point very strongly in this direction. No sediments are found later than the Utica slate until the post-glacial submergence caused the deposition of the Champlain clays. The region was, therefore, above the sea for an immense period of time and its erosion history is a hard one to read. The close of Ordovician time was the date of uplift; the region was affected by the same movements which caused the Green mountain uplift. But whereas the Vermont region was subjected to great folding and metamorphism, in New York the effect was less pronounced and resulted in faulting only.[1]

These faults are the most conspicuous features of the present topography. They have caused numerous drainage adjustments and have produced most marked effects upon the whole subsequent physiographic history. The faults run in general northeast-southwest directions, and were accompanied by block tilting towards the east. The drainage lines have placed themselves along the fault lines, and the tributaries on opposite sides work against an abrupt fault cliff, or a gentle tilted slope, respectively. Those with the slope for their course have a conspicuous advantage, and have extended their courses much farther back than those flowing in the opposite direction. Some of the above facts were brought out by Professor Brigham,[2] who noted on the maps that the southeastward flowing tributaries had much longer courses.

Throughout the remainder of Palæozoic time the region was a land area, and very little trace of the sequence of events has been found. The time was long enough for many erosion cycles, but such evidence as there is points toward gentle simultaneous erosion and uplift, perfect baselevel being at no time

[1] H. P. CUSHING, "Report on the Boundary between the Potsdam and Pre-Cambrian rocks north of the Adirondacks," *Sixteenth Ann. Rept. N. Y. State Geologist*, 1896.

[2] "Note on Trellised Drainage in the Adirondacks," *Am. Geol.*, Vol. XXI (1898), p. 219.

produced. In the north Dr. Cushing has found indications of two peneplains and two periods of uplift.[1] The upper level is marked by the somewhat uneven sky line of the hilltops; the second by the valley levels. The diversity of altitude indicates that when the earlier erosion period was terminated by uplift, the surface was uneven. The observations of the writer in the south are in complete agreement with those of Dr. Cushing in the north.

The uplift which terminated both the cycles was of a dome-shaped nature, being greatest in the Macy region. The result is that as the central region is approached the valleys grow deeper, the vertical distance between the two levels necessarily growing greater the more nearly the center of uplift is approached. The highest mountains stood out as low monadnocks above both peneplains.

The dates of these two erosion cycles are a matter of much uncertainty. The uplifts which terminated them are certainly of comparatively recent date, since, as observed by Cushing, the axis of elevation is most pronounced, and the fault scarps of the same age are remarkably fresh. Definite correlations cannot be made until the topographic maps are completed, not only for the Adirondack region itself, but for the region connecting the Adirondack with the Appalachian region. There seems a strong probability that the upper Adirondack level will prove to be the northward extension of the Cretaceous peneplain of New Jersey and Pennsylvania.[2] Brigham has suggested[3] that the plateau south of the Mohawk is to be regarded as a possible northward extension of this Cretaceous plain. This plateau, like the Kittatinny peneplain, is almost level, and is cut on soft Palæozoic rocks. As already shown, there is reason to believe that the

[1] "Geology of Franklin County," *Eighteenth Ann. Rept. N. Y. State Geologist*, 1898.

[2] W. M. DAVIS, "The Geological Dates of Origin of Certain Topographic Forms on the Atlantic Slope of the United States," *Bull. Geol. Soc. Amer.*, Vol. II, p. 560.

[3] A. P. BRIGHAM, "Topography and Glacial Deposits of the Mohawk Valley," *Bull. Geol. Soc. Amer.*, Vol. IV, pp. 183–210.

Trenton entirely covered the Adirondacks, having since been removed except in the case of a few outliers. The pre-Cretaceous erosion period reduced the soft rocks of the Appalachian region to almost absolute baselevel; in the Adirondacks the same period sufficed to clean out nearly all the softer rocks from the valleys, and to reduce the more resistant crystallines to a condition of moderate slopes and slight relief. The tilting of the plain in the Adirondacks is such as to bring its level into close relation to those further south as well as to the less certainly Cretaceous peneplain of New England. If this correlation proves to be correct, the dome-shaped uplift of the Adirondacks marks the western and northern corner of a great post-Cretaceous uplift. The lower Adirondack level would correspond to the Tertiary level elsewhere observed.

The age of this lower level in the Adirondacks can be fixed with more certainty. The valley floor on which the drift was deposited consisted of the level described, into which the streams had just begun to incise their channels. They must have been rejuvenated in Pliocene or post-Pliocene time, since they had just begun to lower their levels before the ice invasion. If the rejuvenation of them closed the Pliocene, the cutting of the level must have been in the period immediately preceding, or in the earlier Tertiary.

When the ice invaded the region it encountered a drainage long established and well adjusted, but physiographically young in that the region had recently been uplifted and its streams rejuvenated. After its withdrawal it left the valleys completely drift-filled, and the courses of the rapidly cutting streams determined by the slope of the drift. The resulting drainage modifications are numerous.

Rivers.—The preglacial divides had been determined by two axes of uplift, a north-south and an east-west axis intersecting in the Marcy region. The postglacial divides are of drift, deposited in the old valleys, and although conforming in a general way to the old directions the streams are often in quite new channels. Often a few rods of drift is all that separates St.

Lawrence, Champlain, and Hudson drainage. The principal Adirondack rivers—Raquette, St. Regis, Saranac, Ausable, Boquet, Schroon, Boreas, and Indian—are alike in that their sources lie in chains of lakes which owe their origin to glacial agencies. The stream profiles are convex, indicating a young drainage. The lower courses consist of series of still waters, separated by falls or rapids, the whole system owing its character to the occasional wearing off of the drift. Cushing describes several falls with still waters above and below, whose existence is due to the postglacial uncovering of hard ledges of rock. Obviously any rock is harder than drift, and such a dam and fall will be found wherever any bed rock is uncovered. On the inlet to Paradox Lake is such a fall over crystalline limestone of the Grenville series, which is the softest rock of the region. Obviously these falls are temporary, and will be worn back into gorges accompanying a draining of the lakes, until a mature and concave profile is produced.

Lakes.—Lakes of various origins are present in the Adirondacks, and their study would well repay more careful investigation than has yet been given them. They are commonest along the headwaters of rivers, and are here usually due to some form of drift filling in an old valley. Many other lakes, and those notably the smallest, occupy rock basins. Cushing observes that none such have been found in Franklin county, though he admits the possibility that certain lakes may belong to this category. In the southern Adirondacks rock basins are by far the commonest type; here they are usually associated with faulting, but the smoothed nature of their bounding rocks, and the frequency of scorings, suggest the possibility that ice erosion may have been at least a partial factor.

The western gneissic area of low relief and gentle slopes is pre-eminently a land of lakes. They often occur in chains, connected by short stretches of river. The divides are low and usually of drift. These series of lakes represent broad preglacial river valleys, locally deepened and widened by the ice during its advance, and filled with water-deposited drift during

its period of melting. The result of this combined erosion and deposition is that lake basins are formed in some old channels, while others are completely filled, for considerable distances, and the streams pushed into new courses.

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THE LARAMIE PLAINS RED BEDS AND THEIR AGE.[1]

THERE is not another formation in the entire Rocky Mountain region as conspicuous or as universal as the Red Beds. Go where you will, you find the strata of this dark red formation very near the base of the mountain ranges, often forming conspicuous hogbacks, and furnishing examples of wind erosion seldom if ever equaled. No formation in the arid west is so welcome to a geologist as he enters a field for the first time; for its lithological characteristics are so marked and uniform that it forms a horizon indicator that immediately furnishes a working basis.

From the days of the pioneer geologists in the Rocky Mountains, the majority have assigned the Red Beds to the Triassic. A few have been quite guarded in their opinions, and have given the matter unusual attention; but it has been the consensus of opinion that the formation was barren of fossils, and, since it was usually found above Coal-measures and below Jurassic, that it must be Triassic.

Hayden was the first geologist to publish anything in reference to the Laramie Plains. Unfortunately his observations were of the roughest reconnaissance type. In referring to the geology of the Laramie Mountains he says:[2]

> East of the Big Laramie River, and along the western slope of the Laramie range, the entire series of unchanged rocks are visible, inclining at moderate angles, from the mountain sides. On the west side of this range the slope is more gentle, and the Carboniferous, Triassic, Jurassic, and Cretaceous beds present their upturned edges clearly to the scrutiny of the geologist.
>
> The nucleus is red syenite for the most part, while from the margins

In referring to the structure of the same region, in the same report, he says:[3]

[1] Published by permission of the director of the United States Geological Survey.

[2] HAYDEN, *Second Annual Report*, p. 89. [3] *Ibid.*, p. 82.

incline, from either side, unchanged rocks belonging to the Carboniferous, Triassic, Jurassic, Cretaceous, and in some localities Tertiary.

In both of these references Hayden took it for granted that the Red Beds were Triassic.

The next important geological contribution to science in reference to the Laramie Plains Beds appears in the *Systematic Geological Report of the Fortieth Parallel Survey*, under the heading of "Triassic," pp. 249, 250, which reads as follows:

Directly overlying the Palæozoic limestones, in conformable superposition, and not infrequently overlapping the Palæozoic, and coming directly into nonconformable contact with the Archean, appear the well-known Rocky Mountain Red Beds, which, from their position between the Coal-measures below and the well-recognized Jurassic beds above, have been generally assigned to the Triassic age. Reserving all discussion of the validity of this assignment to later pages of this chapter, it is proposed here to give simply a brief statement of their physical condition and continuity along the flanks of Colorado Range within the field of this exploration. From the lower limit of the map nearly up to the forty-first parallel, the Red Beds lie directly upon the Archean, and form, with soft, friable strata, a remarkable contrast with the adjoining crystalline rocks, the red series varying in thickness from 300 to 850 feet. It is interesting to observe that where they are in direct contact with the Archean rocks they have a dip rarely exceeding 15 degrees, and often retaining an approximation to the horizontal; while to the north, where erosion has been deep enough to reach and uncover the Palæozoic series, the dip increases to the vertical, with exceptional instances of slightly reversed position. The region of contact between the Trias and the Archean affords an interesting display of the mode of deposition of the coarse, friable gravel and sandy material of the Trias upon the hard irregularities of the crystalline series.

In the same chapter, pages 256–58, King refers to the Red Beds in the southern portion of the Laramie Plains as follows:

South of the railroad on the western side the contact of the Trias with the Archean is rather interesting. It is seen gradually to overlap the gentle inclinations in thin beds, and to abut squarely against the steeper slopes of the Archean. In general, it dips gently away from the Archean, the Trias ridges being defined by the harder beds which have protected from erosion the softer and more shaly portions below; and wherever there are lines of erosion parallel to the contact-line with the Archean, the steeper or more escarped faces are turned toward the range.

Gypsum deposits are well shown north of the Willow Creek and the

North Park road, where they occur through a thickness of at least 80 or 100 feet, and are interstratified with dark, intensely red sandstones. South of the road are some remarkably eroded forms suggestive of ruined cities.

West of Antelope Creek the Trias extends twelve miles to the south of the Wyoming and Colorado boundary, filling a bay-like depression in the Archean body. Here are exposed, along the eastern side of Laramie Valley, 1,200 feet of beds having a very slight dip to the north and west, a high, abrupt wall of nearly 1,000 feet presented toward the plains. Upon the front of this escarped precipice may be seen the interstratified marls and limestones of the Jura, overlying the heavier red gypsiferous beds of the Trias. In contact with the Archean body the sandstones are of coarse, ash-colored materials containing angular fragments and rounded pebbles, with more or less calcareous matter in the cement, followed by a hard, thin, cherty limestone which passes up into reddish-gray sandstone, and above this the usual beds of coarse red sand, with numerous red clay beds, varying shaly, which give a prevailing argillaceous character to a wide zone of sandstone. Within this red argillaceous series are thin beds of pure clay and white gypsum, the latter varying from two or three inches up to several feet, with one solid body of twenty-two feet inclosed between two series of intensely red, dark, indurated sand-rock. Above the gypsiferous zone occur heavy red sandstones, which pass through yellowish friable beds with marly intercalations into the calcareous beds of the conformable Jura.

The following section illustrates the chief features of the Triassic series, as displayed here, beginning at the summit:

1. Yellowish-red sandstone, passing down into fine, deep-red, evenly bedded, strongly coherent sandstone - - - - - - - - - - - 375 to 400 feet.
2. Argillaceous shales and argillaceous sands, with interstratified layers of fine pure clay, the whole prevailing red, with grayish and yellowish-red zones carrying four or five beds of gypsum, one reaching twenty-two feet in thickness; in all 150 feet.
3. Red compact sandstones, beds of varying thickness, some coarser and some finer - - - - - - - - - - - - - - - 250 feet.
4. Reddish-gray sandstones carrying a bed of cherty limestone four or five feet thick; the whole - - - - - - - - - - - - - - 175 feet.
5. Coarse, friable, ash-colored sandstones of remarkably loose texture, matrix containing more or less calcareous matter, with sheets of pebbles, partly rounded and partly angular cherty masses, together with some fragments of Archean schists, both hornblendic and granitoid - - - - - - - 150 to 200 feet.

There is no question but that King visited the Red Mountain area while making his survey; for there is no other place on the Laramie Plains where the Red Beds rise in nearly vertical walls upward of 500 feet. At the beginning of the chapter from which the above extracts were taken King states that he will

discuss the validity of the term "Triassic" as applied to the Red Beds at the close of the chapter, but I have failed to find his reference.

A portion of the Red Beds of the Laramie Plains occupies a belt of varying width along the western base of the Laramie Mountains. North of Laramie for a distance of forty miles the width varies from three to four miles, and the surface is gently rolling to within a short distance of the range, where there are now and then low hogbacks that have been cut with transverse gulches. South from Laramie the width gradually increases, and at Red Buttes is about six miles, and the eastern portion is marked with a great many eroded buttes which rise from 15 to 50 feet above the surface. Almost due south from Red Buttes there is a long, narrow spur of Archean rocks known as Boulder ridge, projecting into the valley country, causing the Red Beds to narrow down to about three miles. North and east of the Archean exposure there is a tongue-like mass of Red Beds extending into a depression in the Archean to the south of Tie Siding, and, if the width of the formation east and west is estimated from this place, it will be over twelve miles. Southward from Boulder Ridge the Red Beds widen rapidly toward the Colorado line, and near that place have an east and west expansion of about eighteen miles. In Colorado they form a narrow, V-shaped mass that occupies the angle at the intersection of the Laramie and Medicine Bow Mountains; but are nearly covered with Jurassic and Dakota formations.

Generally speaking, the topography of the Red Beds on the Laramie Plains is quite level or gently rolling. Occasionally the hogbacks are found near the ranges, and in three localities the surface is characterized by numerous buttes that have been worn into grotesque figures by wind erosion. These localities are Red Buttes, at the termination of Boulder Ridge and Sand Creek. In the latter place the wind-sculptured rocks are scattered along the valley for a distance of six miles, and present some of the most remarkable examples of wind erosion known in the state. The general forms are irregular domes of cross-

bedded red sandstone, which rise from 20 to 75 feet above the valley. These are occasionally consolidated into a wall with vertical sides, and this capped with grotesque figures altogether too complicated to admit of description here. The west winds cut notches, gaps, and in some places channels, to a depth of 20 or more feet. There are isolated, irregular towers that rise from 50 to 75 feet, and in some instances these have been nearly undermined by the greater erosion at their base, and in a few places they are found already tumbled to the ground. On Sand Creek, and on the Colorado-Wyoming line, Chimney Rock, with its curious rugged exterior, rises to a height of 350 feet above the stream that flows at its base.

The geological section that follows extends from the Archean mass east of Sand Creek, westward to and including Red Mountain, and has been constructed as follows: Nos. 1 to 44 inclusive, were measured on the eastern side of the formation. To the westward the gypsum and aragonite beds were found in the Payne ranch; but the thickness of the formation between the gypsum and No. 44 was not taken, nor were the Red Beds measured above the gypsum in this locality. Red Mountain has been faulted up so as to expose all of the Red Beds from below the gypsum beds upwards, and on account of the accessibility of this section the measurements from No. 44 upwards were taken at this point. The two sections have not been accurately put together, since it was impossible with limited time to locate the upper portion of the first part of the section at Red Mountain.

While at work during the last of November in the vicinity of Red Mountain, I discovered a fauna in the midst of the Red Beds, and to make its position clear I append the following section:

GEOLOGICAL SECTION.

	Feet.	Inches.
Archean granite, badly decomposed, base of Red Beds	10	0
1. Conglomerate, shading into coarse sandstone of a reddish-brown color	1	6
2. Fine grained reddish conglomerate and sandstone	17	0
3. Soft sandstone, shading from gray to red	25	4
4. Whitish sandstone, with a few thin bands of red	2	6

	Feet.	Inches.
5. Thin-bedded reddish and whitish sandstone	1	6
6. Reddish argillaceous sandstone	12	10
7. Whitish sandstone and conglomerate	2	9
8. Soft, maroon-colored to whitish argillaceous sandstone	1	5
9. Coarse light-gray sandstone	0	9
10. Alternating bands of grayish to maroon-colored sandstone	15	3
11. Mottled sandstone, red with greenish-white blotches	3	9
12. Red shaly sandstone	1	5
13. Drab calcareous sandstone	1	2
14. Maroon-colored to light colored soft sandstone	2	4
15. Reddish sandstone, with light-colored small circular patches	0	7
16. Coarse-grained sandstone, very soft, mostly light-colored with reddish streaks	20	2
17. Coarse-grained sandstone, with a few bands of greenish-gray conglomerate	19	3
18. Dark-red sandstone, blotched with greenish gray	3	3
19. Fine-grained conglomerate, grayish, with cross-bedded red strata	2	9
20. Reddish conglomerate, cross-bedded with many angular fragments	26	4
21. Red sandstone and fine-grained conglomerate with whitish bands, only partially exposed	27	1
22. Dark gray to brown sandstone	1	6
23. Maroon-colored to whitish, soft, thin-bedded sandstone	37	11
24. Red shaly sandstone	3	8
25. Red and whitish cross-bedded sandstone	13	5
26. Red sandstone, with pebbles at base	4	0
27. Fine-grained cross-bedded conglomerate	3	10
28. Red to gray sandstone, evenly bedded, with large fragments of plant(?) remains. These are found to lie conformable to the bedding plains, and are from two to four inches in diameter and often several feet in length	21	5
29. Red sandstone, rather hard	9	0
30. Red coarse-grained cross-bedded sandstone, with flint nodules and grayish-green patches	11	0
31. Red sandstone	9	7
32. Red to brownish sandstone, with a few lighter-colored streaks	19	8
33. Red sandstone, with drab particles near the top	1	2
34. Coarse-grained cross-bedded red sandstone	6	2
35. Dark red sandstone, with light-colored streak	12	4
36. Red to gray cross-bedded sandstone	2	3
37. Fine-grained light sandstone	2	7
38. Coarse red sandstone and conglomerate	10	5
39. Dark red sandstone, rather hard, and in strata varying from 8 to 22 inches in thickness	15	8
40. Shelly drab limestone	2	2

	Feet.	Inches.
41. Brick-red sandstone, massive and thick bedded at base; changing to exceedingly cross-bedded structure above. This band weathers into the most peculiar wind-carved figures, which are so common along Sand Creek, where there are several hundred of them. The usual form is a dome, but there are columns, spires, arches, and figures altogether too numerous to refer to here. In reality this band weathers with a peculiar topography which can be easily traced	51	7
42. Whitish and red shaly sandstone, light bands alternating with the red	61	8
43. Red shaly sandstone, capped with 2 feet of hard red sandstone	34	7
44. Red sandstone, mottled with grayish-green blotches. The surface talus covered, and detailed measurements could not be made	151	8
There is an interval at this point in the section that has not been measured; but the thickness is of slight importance and will not amount to 50 feet.		
45. Red sandstone	15	0
46. Greenish to gray soft sandstone	20	0
47. Grayish to reddish sandstone, containing the following genera of fossils: Allorisma, Pleurophorus, Bellerophon, Myallina, Aviculopecten, Dentalium(?), Pleurotomaria(?), several small gasteropods, and some remains of vertebrates	1 to 4	0
48. Gypsum bed, excellent quality	50	0
49. Red clay and gypsum strata alternating, and one of the clay bands containing innumerable aragonites (pseudomorphs after hanksite)	20	0
50. Red sandstone and shale	100	
51. Gray wavy-bedded quartzite	3 to 5	0
52. Red sandstone and shales. Light red and shaly at base; heavy bedded and dark maroon-colored near the top, with no change in general coloration	675	0
Total	1,578	2

Measurements from 45 to 52, inclusive, are subject to revision.

The genera referred to in No. 47 are so characteristic that it is not necessary to discuss their geological position; they belong to the Palæozoic, and resemble to a marked degree the fossils of the Kansas and Nebraska Permian. This places all of the strata below the fossiliferous band in the Palæozoic. There remains a formation of about eight hundred feet in thickness, with the gypsum beds at its base in a questionable position, and some may wish to retain these beds in the Triassic.

All of the pioneer geologists who studied the Laramie Plains

commented on the Red Beds resting on the Archean south of the Union Pacific railroad, and also upon the conformable contact of the Red Beds and the limestones further northward. From my recent investigation I have found that the limestones shade almost imperceptibly into the red sandstones, and that the strata of the lower portion of the Red Beds are identical with the strata of limestones to the northward, the difference in the lithological characteristics being due to the varied physical conditions during sedimentation. Here is a very peculiar instance where rocks of the same age, and, in fact, identical strata, have been differentiated on purely lithological grounds. Just what proportion of the Red Beds will be equivalent to the limestones has not been determined; but probably not less than five hundred feet of the strata near the Colorado line will correspond to limestones and light-colored sandstones some fifteen or twenty miles to the northward, and possibly a greater thickness.

From the data in hand it will be observed that physical conditions favoring the deposition of Red Beds had been in existence for a long time prior to the forming of the fossiliferous band containing the Palæozoic fossils. Above the fossiliferous horizon the formation is made up of the same, or similar, red sandstones and shales; but it is more uniform in color and persistent in its lithological characteristics, and to the northward these strata do not merge into limestones. On the other hand, the Red Beds are conformable throughout, and there is no line of demarkation discovered thus far that would act as a basis of subdivision. There are a few beds of gypsum and limestone, but these are not persistent enough to be utilized as boundary lines. For the above reasons I am in favor of placing the Red Beds in the Palæozoic.

From a palæontological standpoint, likewise, it seems advisable to refer the Red Beds to the Palæozoic. The fauna referred to is purely Palæozoic, and without the slightest evidence of Mesozoic types. It would be unreasonable to expect that a Mesozoic fauna could have developed from the one referred to

in No. 47 in the little time required to have accumulated eight hundred feet of gypsum and sandstone. I realize that this is based purely upon theory; but nevertheless it seems advisable at this time to offer this suggestion. If adopted, it will deprive the eastern Rocky Mountain region of the term "Triassic," and make the basal member of the Mesozoic the Jurassic. Further west, especially along the flanks of the Wasatch Mountains, there are undoubted Triassic beds.

A second question to settle will be the position of these Red Beds in the Palæozoic. Already the limestones along the Laramie Mountains have been referred to the Upper Carboniferous by several geologists; but upon very slight palæontological evidence. None of the early investigators were able to find many fossiliferous bands. In recent years I have found quite a fauna in the limestones, and this resembles the Kansas and Nebraska fauna of the Permian. The fossiliferous bands are near the top of the formation, and there may be typical Coal-measure fossils below; but such have not been discovered, and I am inclined to believe that the limestones of the Laramie Mountains correspond very nearly with the Permian of the Missouri Valley. The Red Beds merge into the limestones or rest conformably upon them, and here we have conditions very similar to those that have been recently discussed from southern Kansas and to the southward. From our present knowledge, it seems advisable to refer the Red Beds of the Laramie Plains to the Permian. This classification has been suggested to me before. Only a few years ago Dr. Williston, while making me a visit, remarked: "Why do you not place the Red Beds in the Permian?" I stated "that we had never been able to discover any fossil remains to guide us in identifying them as Permian." At the time he advanced the idea that the Red Beds in Wyoming were very much like the Red Beds of Kansas.

Further evidence concerning the fossils may be looked for, and I believe that many more localities will be found where fossils have been preserved that will materially aid in the future work. The finding of vertebrate remains is also of importance.

The bones found are so fragmentary as to be beyond identification; but further search will, beyond question, yield better results. The invertebrates have been placed in the hands of Dr. Girty, of the United States Geological Survey, for study, and as soon as he has finished his work there will be a joint paper published that will consider the limestones as well as the Red Beds of the Laramie Plains and their geological position.

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UNIVERSITY OF WYOMING,
March 18, 1902.

THE COMPOSITION, ORIGIN, AND RELATIONSHIPS OF THE CORNIFEROUS FAUNA IN THE APPALACHIAN PROVINCE OF NORTH AMERICA.

THE Devonian was pre-eminently a period of provincial development of marine faunas. In the Appalachian Province of North America, lying to the west of the ancient Appalachian land and to the east of the Wisconsin-Ozark land, there were introduced successively, with little or no foreshadowing, the Helderbergian, Oriskany, Corniferous, Hamilton, and Upper Devonian faunas. Each of these faunas possesses characteristics peculiar to itself which could not have been derived from the next preceding fauna, but which must have been in process of evolution during a long period of time in some other region of the earth. It is perhaps not too much to assume that each of these faunas had its ultimate origin from the earlier, more cosmopolitan fauna of Silurian time, and that their evolutions were in progress contemporaneously, each in its own more or less isolated province. Their succession, therefore, in the Appalachian Province may be entirely accidental rather than genetic.

The amount of faunal change initiated with the introduction of these various faunas differs greatly in degree. In the case of the Hamilton fauna, there are a large number of species which are common also to the preceding Corniferous fauna; in fact, the great majority of the members of the Hamilton fauna are a residuum or an evolution product from the Corniferous fauna. The number of strange forms[1] introduced is small, but they are of such a nature as to show the presence at this time of a means of communication between the Appalachian province and a southern hemisphere province, probably in South America. The presence of these forms, with the internal changes which

[1] The chief of these exotic Hamilton species are *Tropidoleptus carinatus* Con., *Vitulina pustulosa* H., and *Chonetes coronatus* Con.

were in progress, serves to give a character to the Hamilton fauna which is unmistakable.

The faunal change at the opening of the Upper Devonian was far more profound than that which initiated the Hamilton, and it has been shown by Williams,[1] that the foreign element in these faunas, initiated in the Cuboides fauna of the Tully limestone in New York, had its origin in the Middle Devonian faunas of the Eurasian province, and that it found its way into the Appalachian province by way of the Mackenzie Valley of Northwestern Canada, southeastwardly through Manitoba and Iowa.

The life changes introduced with the Corniferous fauna were perhaps even more profound than the changes which took place with the introduction of the Eurasian faunas at the opening of Upper Devonian time. The Corniferous fauna is a large and varied one, and is one of the most widespread of the Devonian faunas of the Appalachian province. Strata containing the fauna are present in New York, where the formation is known as the Onondaga limestone. In Ohio the fauna occurs in the Columbus limestone, and in southern Indiana and Kentucky in the Jeffersonville limestone. The fauna occurs also in southern Illinois near Grand Tower, and reaches as far to the north as northern Michigan. It occurs also in Ontario, to the north of Lake Erie. The fauna has its best development in the central portion of the province, especially in central Ohio and in the neighborhood of the falls of the Ohio River.

The most comprehensive list of invertebrate species occurring in the fauna in the central portion of the province is that which has been published by Whitfield[2] for the region about Columbus, O. It does not, perhaps, contain the names of all members of the fauna as it occurs throughout the entire province, but it is a representative list, and will serve the purpose of making comparison between this fauna and the preceding Oriskany fauna. For a revised list of the vertebrate genera of the fauna I am indebted to Dr. C. R. Eastman, of the Museum of Comparative Zoölogy at Cambridge. The list of

[1] *Bull. Geol. Soc. Am.*, Vol. I, p. 481. [2] *Geol. Surv. Ohio*, Vol. VII, pp. 434–40.

Oriskany species used for comparison with the Corniferous fauna is the one prepared by Schuchert.[1] In this Oriskany list, however, the forms occurring only at Cayuga, Ontario, have been eliminated, for reasons that will appear later, as they cannot be considered as being members of the pure Oriskany fauna. In both the lists some changes in nomenclature have been made, in accordance with recent usage. Only the genera are recorded, the number following each generic name indicating the number of species.

COMPARATIVE LISTS OF THE CORNIFEROUS AND ORISKANY FAUNAS.

CORNIFEROUS.		ORISKANY.	
PORIFERA.			
Receptaculites	1		
HYDROZOA.			
Stromatopora	5		
Cannopora	2		
ANTHOZOA.		ANTHOZOA.	
Favosites	7	Favosites	2
Michelinia	2		
Emmonsia	1		
Trychopora	1		
Aulopora	3		
Syringopora	3		
Eridophyllum	3		
Stylastrea	1		
Zaphrentis	5		
Cyathophyllum	2		
Hadriophyllum	1		
Heliophyllum	2		
Aulocophyllum	1		
Cystiphyllum	2		
ECHINODERMATA.		ECHINODERMATA.	
Megistocrinus	1	Homocrinus	1
Dolatocrinus	2	Mariacrinus	4
Nucleocrinus	1	Edriocrinus	1
Codaster	1	Anomalocystites	1
Ancyrocrinus	1		

[1] *Ann. Rept. N. Y. State Geol.*, for 1888, pp. 52–54.

BRYOZOA.		
Stictopora	1	
Lichenalia	1	
BRACHIOPODA.		BRACHIOPODA.
Orbiculoidea	1	Orbiculoidea 1
Crania	2	Pholidops 2
Rhipidomella	2	Rhipidomella 2
Schizophoria	1	Dalmanella 1
Orthothetes	2	Anoplia 1
Stropheodonta	6	Stropheodonta 4
Strophonella	1	Strophonella 1
Leptaena	1	Leptaena 1
Pholidostrophia	1	Hipparionyx 1
Chonetes	5	Chonostrophia 1
Productella	1	Metaplasia 1
Spirifer	12	Spirifer 6
Reticularia	1	Reticularia 1
Cyrtina	1	Cyrtina 1
Meristella	2	Meristella 4
Nucleospira	1	Rhynchospira 1
Atrypa	1	Anoplotheca 3
Camarotoechia	4	Camarotoechia 2
Rhynchonella	1	Rhynchonella 6
Pentamerella	1	Eatonia 4
Eunella	1	Rensselaeria 4
		Megalanteris 1
		Beachia 1
PELECYPODA.		PELECYPODA.
Aviculopecten	2	Avicula 3
Pterinea	1	Megambonia 2
Mytilarca	2	
Conocardium	1	
Goniophora	1	
Paracyclus	2	
Modiomorpha	2	
Sanguinolites	1	
GASTEROPODA.		GASTEROPODA.
Platyceras	7	Platyceras 10
Platyostoma	1	Strophostylus 4
Euomphalus	1	Cyrtolites ? 1
Turbo	2	
Isonema	3	

GASTEROPODA.—*Continued.*

Xenophora	1
Naticopsis	3
Loxonema	4
Orthonema	1
Macrocheilus	1
Pleurotomaria	4
Murchisonia	3
Dentalium	1
Bellerophon	3

PTEROPODA.

Conularia	1
Tentaculites	1

CEPHALOPODA.

Orthoceras	3
Trematoceras	1
Gomphoceras	4
Cyrtoceras	3
Gyroceras	5

TRILOBITA.

Dalmanites	3
Phacops	1
Proetus	1

VERTEBRATA.

Acanthaspis.
Acantholepis.
Asterosteus.
Cladodus.
Coccosteus.
Cyrtacanthus.
Dinichthys.
Dipterus.
Machaeracanthus.
Macropetalichthys.
Onychodus.
Palaeomylus.
Ptyctodus.
Rhynchodus.

PTEROPODA.

Conularia	1
Tentaculites	1

CEPHALOPODA.

Orthoceras	1

TRILOBITA.

Homalonatus	2

The conspicuous elements in the Corniferous fauna, when compared with the Oriskany, are the great abundance of corals and the large number of fishes. There is also a very much

larger representation of mollusks in the Corniferous fauna; and even among the brachiopoda, where the two faunas have a greater similarity than elsewhere, they are conspicuously different, especially by reason of the absence from the later fauna of genera which were conspicuous in the earlier one. Corals were practically absent from the Oriskany fauna, but in the Corniferous they are everywhere present, usually in abundance, and in some portions of the province they must have grown in great coral reefs. The cephalopods are among the rarest of fossils in the Oriskany fauna, but in the Corniferous there are many of them, often of large size, among which are present straight, curved, and closely coiled forms. Both in its coral element and in its cephalopod element, as well as in the remaining mollusks, there is a strong suggestion in the Corniferous of a recurrence, with profound modifications to be sure, of the more ancient Niagaran fauna, which had occupied the same province at an earlier period. It is altogether probable that the Corniferous fauna was in large part truly an evolution product from the Niagaran, after that fauna had withdrawn from the interior and had become isolated in some province upon the border of the continent after the close of Silurian time.

In its geographic distribution the Corniferous fauna is practically limited to the Appalachian basin in all directions except to the north. The fauna is not known to occur to the east or south of the Appalachian land, which formed the barrier to the interior basin in those directions. Neither does it extend beyond the Wisconsin-Ozark barrier, which was the western boundary of the basin. To the north, however, the fauna occurs beyond the interior province, in the Hudson's Bay basin, which then, as now, was probably connected with the Arctic basin. In a "provisional list of fossils collected between the Long Portage of the Missinaibi branch of the Moose River and Moose Factory," Whiteaves[1] has recorded a list of thirty-three species. Among these are some thirteen corals belonging to genera and species which occur commonly in the Corniferous fauna of the Appala-

[1] *Geol. Surv. Canada*, "Rept. of Prog. 1877-8," p. 50.

chian province, and the associated species are such as to leave no doubt in regard to the entire fauna being a representative of the Corniferous fauna of the interior basin. In another place, from the same general region, Whiteaves[1] has recorded a fauna of ten species with the following remark:

> The fossils described or mentioned above show clearly that the rocks from which they were collected are of Devonian age, also that they belong to the horizon of the Corniferous limestone.

Of these ten species, six are corals, and one, *Macropetalichthys sullivanti*, is one of the most characteristic of the fishes found in the fauna in Ohio.

The Devonian faunas of the Arctic region are practically unknown, but two genera of the Corniferous fishes of the Appalachian province, *Acanthaspis* and *Onychodus*, are known to occur in the Devonian strata of Spitzbergen.[2] Nine of the total thirteen genera are also known from the middle Devonian of the Eifel region of Germany, and three from Bohemia. Many of the invertebrate members of the Corniferous fauna also have representatives in the middle Devonian faunas of central Europe.

From the geographic distribution of the Corniferous fauna, it may be suggested that the province in which it originated was situated somewhere in the Arctic regions, and that representatives of it migrated southward both into North America and into Europe. It has been suggested elsewhere[3] that the typical Niagaran fauna, as it exists in the Appalachian province, came into the region from the north through the junction of the Hudson's Bay basin with the interior basin, and, when it withdrew from the interior, it doubtless followed the same route by which it had entered. During the period of disturbance or readjustment between Silurian and Devonian time it is not improbable that the restricted Niagaran fauna became isolated in the Arctic region, and that from the elements of this fauna, during a long period of time, the Corniferous fauna evolved. This hypothesis,

[1] *Geol. Surv. Canada*, "Rept. of Prog., 1875–76," pp. 316–20.

[2] Private communication from Dr. C. R. Eastman.

[3] JOUR. GEOL., Vol. VII, p. 692.

however, does not account for the remarkable vertebrate element in the Corniferous fauna, as there was nothing in the Niagaran fauna which could have given origin to it. It is possible that the fishes of the Corniferous fauna originated from some fresh water fish fauna which was forced to adapt itself to marine conditions with the encroachment of the Corniferous sea upon the land. During the Corniferous epoch, in the Appalachian province, communication was again established over the same route by which the Niagaran faunas had found their way into the interior basin.

The relationship of the Corniferous to the Oriskany fauna at Cayuga, Ontario, also bears upon the point of entrance of the Corniferous fauna into the Appalachian basin. This locality is approximately the most northwestern extension of the typical Oriskany fauna, and is where it approaches most closely to the hypothetical point of entrance of the younger fauna. Here the two faunas become intimately commingled, a large number of the typical corals, besides other Corniferous types, being associated with such characteristic Oriskany species as *Spirifer arenosus*, *Hipparionyx proximus*, *Anoplotheca flabellites*, etc., as if it were here that the Corniferous fauna first came in contact with the Oriskany. It is because of this relationship that the species found in the Oriskany fauna only at Cayuga, and not further east, have been eliminated from the preceding list of Oriskany species given for comparison with the Corniferous fauna, it being assumed that they were not members of the true Oriskany fauna, but were representatives of the immigrating Corniferous fauna.

In the Devonian faunas of the Eureka District of Nevada,[1] many representatives of the Corniferous fauna of the Appalachian province have been recognized. Among these are several of the characteristic corals, although but few of the fish remains have been detected. In the Kanab Cañon of northern Arizona,[2] however, which is situated in the same Great Basin province, a strongly marked horizon of Devonian fishes has been

[1] WALCOTT, *Monog. U. S. Geol. Surv.*, Vol. VIII.

[2] *Monog. U. S. Geol. Surv.*, Vol. VIII, p. 7.

recorded. That the Great Basin province had communication with the original province in which the Corniferous fauna had its development, is quite certain, although there was probably no direct communication between the Great Basin and the Appalachian provinces, notwithstanding the identity of many species in the two regions.

There are also present in the Devonian faunas of the Great Basin province many species which are identical with Hamilton species in the Appalachian province, but they do not occur at any definite horizon in the Devonian of the region, but are distributed from the bottom to the top. Among these species, however, in no case has there been recorded any of the typically southern hemisphere forms which are so characteristic of the Appalachian Hamilton fauna, all of the Hamilton species in the Great Basin Devonian being such as doubtless had their origin from members of the Corniferous fauna, and it is probable that the Great Basin province never had communication with the Southern Hemisphere province which sent its immigrants into the Appalachian province during Hamilton time.

In the Devonian faunas of the Iowan or Northwestern province there is an element so strongly suggestive of the Corniferous that Dr. Barris[1] at one time went so far as to refer some of the Devonian beds of eastern Iowa to the Corniferous. That there is a Corniferous element in these faunas, exhibiting itself especially among the corals, cannot be denied; but associated with this element, either directly or in accompanying strata, there is another element so entirely foreign to the Corniferous that the reference of any of the Iowan Devonian strata to the Corniferous cannot be entertained. The Eurasian origin of the characteristic element of the Iowan Devonian faunas and of the upper Devonian faunas of the Appalachian province has been established, and the pathway of communication from the Eurasian to the Appalachian province was through the Mackenzie basin of the northwest, which doubtless communicated with the Arctic province where originated the Corniferous fauna. It is

[1] *Proc. Davenport Acad. Nat. Sci.*, Vol. II, p. 261.

not strange, then, that some elements of the Corniferous fauna became mingled with this Eurasian fauna as it migrated toward the Appalachian province. This will account for the presence of a considerable number of species which are common to both the Appalachian Hamilton and the Iowan faunas. In all cases these species are forms such as *Cyrtina hamiltonensis*, *Pholidostrophia iowensis*, *Stropheodonta demissa*, etc., which either were present in the Corniferous fauna, or had their nearest allies in that fauna. In the case of the genus *Schizophoria* we have an example of a form which was well represented in the Cornifersus fauna by the species *S. propinqua*, but which became almost extinct in the Appalachian Hamilton fauna, to be reintroduced into the Appalachian province with the opening of Upper Devonian time by such species as *S. tulliensis* and *S. striatula*.

In the Great Basin province the two Devonian faunas having a definite stratigraphic sequence are first, the fauna with Corniferous affinities in the lower strata of the section, and, second, the Eurasian fauna allied to that of the Iowan and the upper Devonian faunas of the Appalachian provinces. Both of these faunas doubtless entered the region by the same route from a nearly north direction.

The value of any hypothesis proposed for the explanation of natural phenomena must rest upon the number and variety of observed facts for which it offers an explanation. The hypothesis that the Corniferous fauna had its origin in an Arctic province seems to afford an explanation for many facts relative to the geographic distribution and the faunal relationships of some of our Devonian faunas in America, and may thus stand as a working hypothesis which future observations will either strengthen or overthrow.

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EDITORIAL.

WITH this number of the JOURNAL there appears the first section of a series of articles of more than ordinary moment to petrographers. The initial article by Mr. Cross is the first installment of a historical review of the various systems of classification of igneous rocks developed in the nineteenth century. This essay is the result of a conscientious and critical study of petrographical classifications in their historical aspects, and presents an admirable synopsis of this complicated subject. Quite by itself it will certainly be found of great service to students of petrography in furnishing them with a perspective view of the growth of our present unsatisfactory system. The second part will appear in the next number of the JOURNAL.

Aside from its inherent interest, a special value lies in its introductory relations to a still more important essay on "A Classification and Nomenclature of Igneous Rocks," which will occupy the whole of the sixth number of the JOURNAL. The system proposed in this article is the outcome of some years of collaboration by Messrs. Cross, Iddings, Pirsson, and Washington, and represents the united judgment of these experienced petrographers. The system is radically different from those in present use, and the nomenclature is new. The self-abnegation shown by these four petrographers in merging their individual views and preferences in a common effort to produce a working system in advance of the present unsatisfactory one is a pleasant token of the healthful relations of petrographic workers.

T. C. C.

Reviews.

Genesis of Ore Deposits. Published by the American Institute of Mining Engineers, New York, 1901. 8vo., 806 pages, illustrated. Price, $6.00.

The compilation and republication of the papers recently presented to the Institute, and bearing on the genesis of ore deposits, has resulted in a notable volume. Beginning with the famous treatise presented by Professor Franz Pošepnỳ at the Chicago meeting of 1893, and including the discussions at that and the succeeding meetings at Virginia Beach, Bridgeport, and in Florida, the volume is continued by an important group of papers read at the Washington meeting in 1900, with the succeeding discussions. It is concluded by a bibliography of additional papers on the same subject, read before the Institute, of 188 titles. The showing is a most remarkable one, and the volume includes a statement of almost every advance in knowledge of the principles of ore genesis made in America within the last ten years; not that in every case it is the fullest statement of the authors' views made here, but practically every advance made within that period in the study of American ore deposits, aside from regional work, is represented by an author's statement. The most notable exception is the comprehensive and valuable paper by Mr. Penrose on the "Superficial Alteration of Ore Deposits," contributed to this Journal in 1894.[1] In all, twenty-two contributors are listed in the table of contents of the volume. There are eleven general papers and twenty-one criticisms or discussions. The full list of authors is as follows: R. W. Raymond, Franz Pošepnỳ, W. P. Blake, Arthur Winslow, T. A. Rickard, Horace Winchell, John A. Church, S. F. Emmons, G. F. Becker, F. M. F. Cazin, Joseph LeConte, C. R. Van Hise, Walter Harvey Weed, Waldemar Lindgren, R. Beck, L. de Launay, Arthur L. Collins, H. Foster Bain, Charles R. Keyes, Frank D. Adams, J. H. L. Vogt, and J. F. Kemp.

Although the whole volume has been edited, much of it translated, and most of it obtained by the personal solicitation of the secretary of

[1] Jour. Geol., Vol. II, pp. 288–317.

the Institute, Mr. R. W. Raymond, it is characteristic of his modesty that his name appears in the volume only among those of the contributors. Nevertheless, in preparing the volume, Mr. Raymond has performed a service which his fellow-workers will more and more appreciate as the work comes to assume its rightful place; that of the standard statement of modern views on ore deposits.

Covering, as it does, practically a decade of discussion, and being made up, as it is, of the statements of so many workers, it is in a peculiar degree a summary of present belief with just enough of discarded theory to give a proper perspective. The period from 1893 to 1901 has been particularly fruitful in the study of ore deposits, and, as is so often true, much of the discussion which has led to the clearing up of certain phases at least of the problem of the genesis of ores, came from the clear and unequivocal statement of an extremist; one, furthermore, whose ideas were radically opposed to those most generally current at the time. Up to 1893 American scientific opinion was strongly committed to the doctrine of lateral secretion; not, however, exactly in the sense proposed by Sandberger in his famous treatise[1] defining that doctrine. A characteristic expression of the broader American view is that of Emmons in his report on the Leadville district.[2] According to this view, ore deposits in general represent concentrations made by underground waters, the material being derived from the leaching of the country rock, not necessarily of the immediate vicinity. The waters were believed to be meteoric in origin, and more or less closely connected with the ordinary surface circulation.

In 1893 Professor Pošepnỳ, with charming spirit, and fortifying his argument with many illustrations drawn from notes accumulated during a long and intimate study of ore deposits, combated this view most vigorously. Beginning with a clear and accurate analysis of the subterranean water circulation, he discriminated sharply a vadose or shallow circulation from a deep circulation, basing the distinction mainly upon the chemical constitution and effects of the two waters; a difference already clearly recognized and made use of in America by both Le Conte and Chamberlain, but not generally recognized as fully as it deserved. As characteristic of the difference between the waters of the two circulations, and most significant for purposes of the discussion, it was pointed out that the water of the vadose circulation in

[1] *Untersuchungen uber Erzgange*, Weisbaden, 1885.

[2] *Monograph XII, U. S. Geol. Surv.*, Washington, 1886.

only the rarest instances deposits sulphides, while these salts are the characteristic deposit of waters of deep circulation. Since the bulk of the ore deposits, neglecting certain clearly recognized but minor classes over which there is no dispute, are made up of sulphides or their alterative products, it was held that the ores must have been made by the deeper circulation, and that the waters making the deposits must have been "ascending." In the earlier portion of the paper there are statements making clear the relations between the two circulations, and showing that one is but the counterpart of the other (pp. 27–28); there are later numerous statements which throw the matter into confusion (pp. 39, 56, etc.) While there is not such a clear statement as would be desirable, we are led to infer that the waters of the deep circulation are in some mysterious way cut off from and different from those of the shallow circulation, and that they are connected with a certain deep region, or barysphere, "the peculiar home of the heavy metals." The existence of this region is inferred from the usual calculations based upon the difference in density between the earth as a whole and the rocks of the surface of the earth. The very existence of a barysphere, in the sense of a central region of the earth heavier by reason of a greater abundance of the heavy materials, is to be questioned,[1] however, on many grounds.

In the discussion of Pošepnỳ's paper, which followed its presentation, some of his criteria were discredited, and Rickard struck the keynote when he stated that neither ascending nor descending was the proper term to apply to the ore-depositing waters, but that circulating was the true descriptive term. This was characterized by Pošepnỳ as "a step backward." The most trenchant and significant criticism, however, was that of Professor LeConte, who showed the great improbability, if not actual impossibility, of any surface waters penetrating to the depth of the assumed barysphere, and who then pertinently inquired, If the waters which deposited the ores were not meteoric in origin, where did they come from? Were they constituent waters originally occluded in the primal magma? This is on its face highly improbable, particularly in view of the fact, so clearly recognized by Pošepnỳ, that any ore deposit necessarily indicates the passage of a considerable body of water through the space now occupied by the ore.

At the close of the discussion, then, we are left with the conclusion that ore deposits, in general, are formed by the circulation of under-

[1] See particularly Arrhenius, as cited by VOGT, *op. cit.*, p. 638.

ground waters, the material being gathered from the rocks through which the waters pass, and that the sulphide ores are formed principally by the returning or ascending portion of the circulation. This conception, amplified and defended with many arguments and examples, is the keynote of the paper by Van Hise, which forms the natural beginning of the second part of the volume. Since Professor Van Hise's views have already been presented in this JOURNAL,[1] no review of them need be made here.

The criticism of Van Hise's views has been principally along two lines: (1) Is the conception presented by him of a universal underground circulation moving in obedience to gravitative stress a true one? and (2) is such a circulation competent to account for ore bodies such as actually occur without calling in the very frequent and active agency of eruptive forces? It appears to the reviewer that, to a considerable extent, the criticism is based upon an erroneous understanding of the hypothesis, and to a minor extent upon a misconception of facts. A universal underground water circulation does not necessarily mean universally saturated rocks. The great difference in permeability of rocks precludes their having an equal water content. If a larger emphasis be placed upon the influence of impervious strata, the supposed difficulties largely disappear. Professor Kemp cites a number of deep workings which are dry (696–701), and states a belief that the amount of water which penetrates to depths is probably comparatively small. Such citations, however, are only significant when the full details of each case are fully understood. For example, the Congress mine in Arizona has been cited, by another, as an instance of a very deep mine which is notoriously dry. The illustration loses its force, however, when it is remembered (1) that the region is one in which the water level is everywhere far below the *present* surface, and (2) that the Congress vein is a very shallow dipping one. "Very deep," as measured along the vein, is, accordingly, not "very deep" as measured vertically. Again the Vindicator, Hull City, and neighboring mines at Cripple Creek go down a thousand feet or more in perfectly dry ground, but they start only a short distance laterally, but at a considerable altitude above Wilson Creek. Furthermore, anyone visiting the workings will at once see the clearest evidence of the former action of underground waters; in this case evidently oxidizing surface waters.

[1] JOUR. GEOL., Vol. VIII, pp. 730–70, 1900.

Perhaps a still clearer example is that of certain mine workings in the Newhouse tunnel at Idaho Springs, Colo. This tunnel is driven north from South Clear Creek a distance of more than two miles under Seaton Mountain and toward Central City. It attains a maximum vertical depth of 1,710 feet, or approximately 2,200 feet, as measured along the dip of the veins. The slopes of the Gem workings in this tunnel are so dusty that there is difficulty in obtaining men who will work in them permanently, yet the month that the tunnel cut through this vein the men had to wear a full outfit of rubber boots, slickers, and rubber hats, and the tunnel drift still yields a notable flow of water. When the Addudle vein was cut, approximately a year ago, there was another small flood, and to this day the vein is raining into the tunnel steadily. In this instance, despite the steady downpour, the old surface workings are as full of water as ever. That the waters encountered in the tunnel belong to the ordinary underground circulation and come from the surface is proven by their oxidizing character. In general, along the tunnel the main flow of water comes from the veins, but nevertheless there seems to be a minor but steady seepage through the country rock. A rough measure of this seepage is given by certain work in the Franklin mine. The first of February, this year, the sixth level yielded a flow of approximately 7,000 gallons per day. Since then the drifts have been extended 250 feet, adding approximately 5,000 square feet of surface for seepage, and not intersecting any important cross veins or fractures, and yet the flow has slightly more than doubled. Since there has been no corresponding increase in the amount of water elsewhere, it seems clear that the larger flow is due to the greater surface. The fifth level of this mine, by the way, since pumping began on the sixth, is dry, but on the first level there is a drift not connected with the lower workings, full of water. Clearly in this case the different portions of the vein matter vary greatly as regards permeability. Cross-cut tunnels generally yield little water except as they intersect fractures; but I know of none which does not have a water box along the bottom and a steady stream of water flowing through it; that is, while the flow is practically confined to the fractures, the rock, measured in bulk, none the less contains water in quantity. The evidence, then, points to a widespread underground circulation, though there are admittedly dry or impervious beds, and admittedly measurable flows are nearly always confined to visible cavities.

It is furthermore pertinent to inquire, with Le Conte, if it be held that the waters from which the ores were deposited do not originally come from the surface, and if the "ascending currents" are not fed by equivalent "descending currents," what is the nature of this water, and whence its source? It is admitted by practically all students of the problem that the deposits in question are the work of waters of some sort.

The question whether the waters derive their motive force from gravitative stress is one which must be answered in each case with an eye to the facts of the particular case. Admittedly the friction between the moving fluid and the walls of the conduit decreases the pressure, and, supposedly at least, the friction might become so great as to wholly stop the flow. In the case of water moving through supercapillary tubes this cannot on the average be true, so long as the distance measured is vertical, and the tubes are approximately regular, since the pressure increases *pari passu* with the friction. The flow is further increased presumably by decreasing viscosity resulting from heat. It may be stated at once that probably, as it seems to the reviewer, the major flow concerned in the formation of ore deposits is that through supercapillary tubes. In the matter of flow through capillary tubes, there is some doubt, since the laws of such flow under high pressure seem not well understood; but if Poisenille's law be applicable, the result must be the same, since the flow is proportional to the pressure itself, which increases directly with the depth. Wherever the underground waters are in motion it is difficult to conceive of their not flowing in obedience to gravitative forces; except in very especial and particular instances where the little understood gaseous pressure may become operative.

In regard to the second question, whether ores are not more directly dependent upon the phenomena of vulcanism than would be inferred from a general reading of Van Hise's paper, it is but fair to state that he evidently recognizes these forces as important, though he devoted more space to less generally recognized phases of the problem. It has been tacitly assumed by all parties to the discussion that heated waters under pressure have been the main agents in collecting the material which makes up the ore bodies. The underground waters may become heated by (1) contact with volcanic rocks recently injected into the outer crust of the earth, (2) by contact with rocks heated by dynamic action, (3) by penetrating to a sufficient depth to absorb heat

from the interior of the earth, and (4) by chemical activity between the water and the material in the rocks. The waters may come under pressure (1) by increasing gravitative stress due to increased head as they gain in depth, (2) by expansion in confined space as a result of heat, and (3) by gaseous pressure, itself perhaps the result of chemical activity. With all these sources of heat and pressure available, the important point is to discover which ones have probably been operative to the largest extent. To the reviewer it seems clear that, as pointed out by Vogt and Kemp, the intrusion into the outer crust of the earth of molten rock from below has probably been the largest single factor in heating the underground waters. The distribution of the mineral districts in connection with the distribution of these eruptives and of hot springs affords a powerful argument for this conclusion. The close association of ore deposits, eruptive rocks, and hot springs has been so often pointed out as to need no further citation. The exceptions, such as the lead and zinc deposits of the Mississippi valley, have uniformly been found on careful study to differ in genesis from the more common type of sulphide ore deposits exemplified in the usual occurrence of the precious metals in the Rocky Mountain region.

A body of molten rock, forced up into the cooler mass above, must produce a profound disturbance of the ordinary underground circulation. Its quickening and vivifying influence is bound to be stupendous, and the marks of the intrusion are apt to be permanent. The underground waters of such a district will be warm for centuries after the magma itself has consolidated and become fixed in form and place. An instructive instance, and one believed not to be exceptional, is that of Idaho Springs, in Colorado. There are here hot springs which presumably are the last surviving mark of volcanic activity in the district. The youngest rocks present are certain andesitic dikes, whose age is approximately fixed by andesitic débris found in Tertiary beds near the mouth of Clear Creek Cañon, at Golden. Since the intrusion of these dikes the whole country has been profoundly sculptured, and the interval must certainly have been a very long one, yet the underground waters, as shown by the hot springs, still penetrate to some portion of the uncooled rock. The ore bodies of the district are closely related to these andesites; indeed, the veins usually occur along the contact of the andesite and the Archean country rock, and in places are merely mineralized portions of the andesite itself. So far as is known there

are no considerable ore bodies in the surrounding Archean not connected in some way with the andesite. Furthermore, no considerable mining district in Boulder, Gilpin, or Clear Creek counties occurs except where these andesites are present, even though the same Archean country rock is everywhere present, and in all probability was subjected to the action of ordinary underground waters for many times as long before the intrusion as after. Under these conditions the connection of the ore bodies with the disturbance of the underground circulation by the intrusion of the eruptive rock can hardly be doubted. The possibility of their being formed by normal underground circulation counts for little as against the fact that, in the long time from Archean to Tertiary, they were not formed, and in the relatively short time since, under the new conditions, they were.

It is equally clear, however, from a study of the ore bodies, that the process of their formation occupied a long period, as measured by ordinary standards. The ores are associated with the most altered portions of the eruptives. They occupy often fissures in the latter which could only have been formed after the rock had consolidated and cooled sufficiently to be amenable to the ordinary stresses existing in the rocks of the surface of the earth. The halogen elements are conspicuously absent, and there is no known reason for inferring that pneumatolitic action was prominent when the ore bodies were formed. It may be added that the veins are typical "fissure veins" carrying sulphide ores; the very class of deposits principally under discussion.

Among the many phases of ore bodies, aside from the problem of their primary genesis, which are discussed in the volume under review, there are none more important than the secondary enrichment of the sulphides, and the metasomatic processes in fissure veins. The first is discussed in separate papers of Emmons and Weed and in portions of papers by Van Hise, Rickard, and de Launay. The second is treated in considerable detail by Lindgren.

Starting from a disposition to question Pošepnỳ's dictum that sulphides were not formed by the waters of the vadose circulation, Emmons, Weed, and Van Hise have independently worked out the process by which the sulphide ore bodies at and near the water level become enriched by material carried down from the oxidized ores above. The process depends principally upon the relative affinity of the various metals concerned for oxygen and sulphur, by which, for example, iron sulphide comes to act as a precipitant for zinc and lead

when the latter are present as a sulphate. The process is well founded on known principles, and the phenomena accounted for are among the most common and heretofore most puzzling encountered in mining. The solving of this difficulty is likely to be of the highest practical utility.

Mr. Lindgren's paper on metasomatic processes gives sharp definition to many heretofore hazy phenomena and will be of considerable utility both in the development of theory and practice.

In general, the volume is notable in that for the first time the results of recent investigations in physical chemistry are applied to the solution of the problems of ore genesis. The results attained are most promising, and open up enticing vistas of what may be expected from further investigations along these lines. For example, the question may be asked whether, in seeking an explanation of the chemical problems involved, we have not relied too exclusively upon the influences of heat and pressure. If we keep in mind the very large place in the field of research which the diminutive ion now holds, and the close relations obtaining between ions and electric forces, one may well question whether here is not a fruitful field for investigation. The startling results already obtained in physiological investigations by studying the operation and effects of the electro-motive force hint at perhaps equally important results awaiting the investigator in other fields.

H. FOSTER BAIN.

IDAHO SPRINGS, COLO.

SUMMARIES OF THE LITERATURE OF STRUCTURAL MATERIALS. I.

EDWIN C. ECKEL.

UNDER this heading the writer purposes to summarize at intervals the literature relating to the economic geology of building stone, road materials, cements, lime, gypsum, clays, etc. Except when the word "comment" expressly appears, the matter presented will be simply a summary of the statements and opinions appearing in the paper under discussion. The writer will endeavor to indicate briefly the scope of each paper, following this by a résumé of the *original* matter contained in it.

BABCOCK, E. J. *Clays of Economic Value (in North Dakota).* First Report North Dakota Geol. Surv. Pp. 27–55, 3 plates, 1901.

The clays of North Dakota are derived from the Pleistocene, the Laramie, and the Fort Pierre division of the Cretaceous. The Pleistocene clays include the yellow

and blue brick clays of the Red River valley; the stoneware clays and fire clays of Dickinson and the clays of Minot and Plenty Mine are probably Laramie; while the shales about Park River and the Pembria Mountains are in the Fort Pierre. Analyses of European and New Jersey clays are quoted, with notes on the qualities requisite for the various clay products. Detailed descriptions of North Dakota clays, with analyses and tests, are then given.

Clays suitable for the manufacture of common brick are widely distributed, and plants are in operation at Fargo, Minot, Bismarck, Burlington, Grand Forks, Drayton, and many other places.

Near Minot, at Bismarck, in Mercer county, and at the Lehigh mine, clays occur which are adapted to use in the manufacture of pipe, tile, and terra cotta. None of these are at present used.

Fire clays and stoneware clays are found at only one locality in the state, near Dickinson, Stark county. These clays are in the Laramie, and outcrop in quantity on the bluffs near the town. A large fire-brick plant is now in operation at this point, the product being of very high grade.

BLATCHLEY, W. S. *Oolite and Oolitic Stone for Portland Cement Manufacture.* Twenty-fifth Ann. Rept. Indiana Dept. Geol. and Natural Resources. Pp. 322–330, Pl. 13, 1901.

Pure limestones occur in Crawford, Harrison, Washington, Lawrence, Monroe, and Owen counties, Indiana. Analyses show that the lime carbonate usually exceeds 95 per cent., with rarely more than 1 per cent. magnesium carbonate. Clays and shales of suitable quality are, in many places, near the limestones. Several companies have been organized to utilize these limestones and clays in the manufacture of Portland cement.

BUCKLEY, E. R. *The Clays and Clay Industries of Wisconsin.* Bulletin 7, Part I, Wisconsin Geol. and Nat. Hist. Surv. 8vo, pp. 304, Pl. 55, 1901.

Chapters on the origin, composition, classification, and properties of clays precede detailed descriptions of the clay deposits and industries of Wisconsin.

Buckley discusses previous classifications and offers a scheme based primarily on origin and secondarily on position:

I. Residual, derived from
   a. Granitic or gneissoid rocks.
   b. Basic igneous rocks.
   c. Limestone or dolomite.
   d. Slate or shale.
   e. Sandstone.
II. Transported, by
   a. Gravity assisted by water.
      Deposits near the heads and along the slopes of ravines.
   b. Ice.
      Deposits resulting mainly from the melting of the ice of the Glacial Epoch.
   c. Water.
      1. Marine.
      2. Lacustrine.
      3. Alluvial.
   d. Wind.
      Loess.

The residual clays of Wisconsin are not of much economic importance except in the driftless area, where clays resulting from the decomposition of limestone are extensively worked for brick manufacture. Glacial clays are important in the northern part of Wisconsin, and include some of the best and some of the poorest clays of the state. In the clays of marine origin are included the shales of the Cincinnati and Potsdam periods. The Cincinnati series has a thickness of 165 to 240 feet, and consists of interbedded limestone and shale. The shale varies greatly in composition and in hardness. Near the base of the Potsdam in the central part of the state occur interbedded layers of very soft plastic blue to brownish clay and coarse sandstone.

The lacustrine clays are perhaps the most extensive in the state. They are partly of interglacial, partly of immediately postglacial age; and in some places the clays and interbedded tills have a depth of one hundred feet or more. This thickness is not composed entirely of water-sorted material, but includes a considerable thickness of bowlder clay with pebbles of igneous rock and limestone.

River deposits of varying age are common, and furnish much clay for brick manufacture. In composition these clays vary with the rocks of the drainage basin in which they were formed, the clays of the west central part of the state being the least calcareous.

In Dunn and St. Croix counties extensive deposits of pure white kaolin occur, probably derived from the igneous rocks to the northeast and deposited by water prior to the first glacial epoch. These clays are of the highest grade, but are now shipped exclusively for use in the manufacture of paper.

Wind-borne clays are of doubtful occurrence, and in the few cases where æolian transportation seems probable, the resulting deposits are of no economic importance.

KÜMMEL, H. B. *Report on the Portland Cement Industry* (in New Jersey). Ann. Rep. N. J. State Geologist for 1900. Pp. 9–101, Figs. 1–33, Pls. 1–2, 1901.

The first chapter of this report is a discussion of the composition and materials of Portland cement in general; the second is devoted to the geologic relations of the Cambro-Ordovician rocks of Warren and Sussex counties; and the third contains detailed descriptions of the areas of Trenton limestone ("cement rock"), with notes on other limestones and the white marl deposits of New Jersey.

Overlying the relatively thin Hardiston (Lower Cambrian) quartzite of the Kittatinny valley is the great magnesian limestone series which has been described as the Kittatinny limestone by Weller and Kümmel, and as the Wallkill limestone by Wolff and Brooks. The Kittatinny limestone is usually blue, though often varying to gray drab, or even black. It is fine, even-grained, often minutely-crystalline. It usually contains 15 to 20 per cent. of magnesium carbonate, and is therefore not available for use in the manufacture of Portland cement.

Resting on the eroded surface of the Kittatinny limestone, and often commencing with a basal limestone conglomerate, is the dark blue, fossiliferous Lower Trenton limestone. Unlike the Kittatinny, it is never magnesian, but many of its beds are shaly. These shaly beds, carrying 65 to 75 per cent. lime carbonate (the remainder being silica and alumina), are the "cement rocks" which form the basis of the great Portland cement industry of New Jersey and Pennsylvania. The lime carbonate needed to carry them up to the proper composition is obtained from other beds (of purer limestone) occurring in the Trenton.

Detailed descriptions, with maps and analyses, of the exposures of Trenton limestone are given in the final chapter of the report. Certain limestones of higher horizons are also discussed in this connection, as are the deposits of white shell marls.

LEE, H. A. *Mineral Resources of Colorado — Larimer County Gypsum.* Stone, Vol. XXI, pp. 35–37, 1900.

Larimer county is the largest gypsum producer in Colorado. The gypsum deposits are associated with rocks of Jura-Cretaceous age, and occur in a basin between rocky ridges. The main quarry is operating on a knoll showing a face of gypsum 250 feet long, and 28 feet high in the middle, thinning to 7 feet at the edges. The gypsum is quite compact and gray in color. The amount of stripping does not exceed 18 inches. The material is blasted out, auger holes being bored to receive the charge of explosive.

The mill of the Consolidated Plaster Co. has a capacity of 40 tons per day of ten hours. It is built on a side hill and the gypsum is received from wagons at the top of the mill, fed through coarse and fine crushers, and then over screens to buhrstone mills. From these it is carried to five-ton kettles, two and a half hours being consumed in charging, "boiling," and discharging. No details are given concerning the retarders used.

MCCALLIE, S. W. *Preliminary Report on the Roads and Road-Building Material of Georgia.* Bulletin 8, Georgia Geol. Surv., 8vo, pp. 264, Pls. 1–27, Figs. 1–28, geologic map, 1901.

The chapters of this bulletin fall naturally into three groups, treating respectively the subjects of road construction in general; the topography and geology of Georgia in relation to road construction and road building materials; and the methods of road making in the various counties of the state. The first of these groups includes chapters on the history of road construction; the value of good roads; the theory of road making, as regards locations, grades, and surfaces; the maintenance and repair of roads; the considerations governing the selection of road materials; and the tools and machines used in highway construction. These chapters furnish an excellent summary of the general subject of road making.

In the second group fall chapters on the topography of Georgia in its relation to the highways, and on the road-building materials of Georgia. A colored map shows the areas covered by the crystalline, the Palæozoic, and the Cretaceous and Tertiary rocks; and the location of the trap-dykes which occur in the crystalline area.

The Palæozoic area is divided topographically, following Hayes, into the plateau, sharp ridge and valley region. The plateaus have a level surface, but terminate in steep escarpments. Owing to the steepness of these escarpments, it is difficult to carry a road by easy grades from the valleys to a plateau, but when the elevated areas are reached the cost of construction is slight. The plateaus also affect road work by acting as barriers to free communication between their bordering valleys. The second type of surface consists of a number of sharp, parallel ridges, trending northeast and southwest, and due to the weathering of the upturned edges of hard sandstone (which, in the plateau region, lies almost horizontal). The smaller ridges are frequently inter-

sected by streams along whose valleys cross country roads of easy grade can be constructed, while the main roads are located in the valleys, which offer no serious obstacle to construction. The valley region consists of low, wide, comparatively level valleys, in which highway construction is simple.

The crystalline area is divided into two regions — the mountainous and the plateau. The former consists of rugged peaks separated by narrow valleys, in which flow rapid streams; and road construction and maintenance is difficult and expensive. In the plateau region highway construction is easy, as light grades can be obtained, and the cost of grading is slight owing to the deep decomposition of the underlying rocks.

The Tertiary area is a plain, sloping gently southward, and traversed by large streams. Swamps and depressions along stream valleys offer the only serious obstacles to road construction which, except in these places, is very inexpensive.

The road materials occurring in the Palæozoic area are limestones, cherts, shales, and sandstones. The limestones of the area are abundant and well suited for road-metal. They are all of the Silurian age, and occur in three different formations; the Knox dolomite, the Chickamauga limestone and the Bangor limestone. Of these the first is the most important, owing to its thickness and areal extent. It is easily quarried and crushed and furnished excellent road metal. Some beds of the Chickamauga formation supply good material, as does the Bangor limestone. The areal extent of this last formation is, however, too small to make it of importance.

The Palæozic cherts are widely distributed and extensively used. They occur in both the Knox dolomite and the Fort Payne chert. The material is well suited to roads of light traffic, but inferior to limestone where the traffic is heavy. It binds well but becomes dusty in dry weather. The chert is often located favorably for working and transportation.

The shales and sandstones of the Palæozoic are locally used, but are not satisfacrory material.

In the crystalline area the rocks available for road work are granite, gneiss, diorite, trap schist, quartzite, and marble. Of these the last three are unsatisfactory as road metals. The granites, and the less well-laminated gneisses and diorites, furnish fair macadam. The trap dikes which are widely distributed in the crystalline area furnish excellent material. These diabases are dark gray to black, fine grained, and very tough. At present this material is little used, but will probably become important.

The Tertiary area supplies limestone, buhrstone, and gravel. The limestones consist of shell fragments, with some sand, in a calcareous matrix. They have been used extensively in southern Georgia, and are very satisfactory, cementing readily into a compact, hard surface, comparatively free from dust. Buhrstone is of little use. The gravels cemented by ferruginous clays make durable and very satisfactory roads, and are largely used.

NEVIUS, J. N. *Roofing Slate Quarries of Washington County, New York.* Nineteenth Rept. N. Y. State Geologist. Pp. 135–150, Pls. 26–37, 1901.

Gives detailed descriptions of the slate quarries and quarry methods and a discussion of the general features and condition of the industry. The working quarries

are located along an approximately north and south line which extends from the Hampton variegated quarries on the north, through the North Bend, Middle Granville, Granville red and the Slateville red and green quarries, and the purple and green quarries of Salem, Shushan and Cambridge. The East Whitehall (Hatch Hill) quarries are west of the northern end of this belt.

The red and green slates are cut to size at the mills. The mottled slates, being unsalable in the natural condition, are "marbleized," an enamel being applied to give imitations of marbles, etc. The refuse from the slate mills is ground and used as a pigment.

PECK, F. B. *Preliminary Notes on the Occurrence of Serpentine and Talc at Easton, Pa.* Annals N. Y. Acad. Sci., Vol. XIII, pp. 419–430, Pl. 16, Figs. 4, 5, 1901,

Chestnut Hill is a pre-Cambrian outlier near Easton, composed of a dense hornblende gneiss with interstratified beds of carbonates. These beds, five to thirty feet thick, consist of pink calcite, gray dolomite, or a mixture of the two. Along a series of thrust faults great shearing has occurred. Hornblende (usually tremolite), phlogopite, and occasionally pyroxene, occur so abundantly in these beds as locally to replace all or most of the carbonates. The calcite dolomite beds shear to a slaty, foliated talcose mass consisting of a mixture of talc, tremolite, serpentine, or without shearing, become changed to beds of nearly pure white tremolite. The phlogopite, which is developed locally in large quantities, alters quite uniformly to serpentine and constitutes the chief source of that material in the eastern quarries. One particularly attractive phase of the material quarried consists of numerous rose-colored dolomite crystals scattered through a mass of serpentine.

RIES, HEINRICH. *The Origin of Kaolin.* Trans. Amer. Ceramic Soc., Vol. II, 1900.

The author defines the kaolins as "those clays which are residual in their nature, and which burn to a sufficiently white color to be used in the manufacture of white earthenware." Thus restricted, two different modes of origin of kaolins are discussed. In most cases kaolin has been derived from the decomposition of a highly feldspathic rock, through the action of surface agencies. Von Buch, Daubree, and Collins have, however, pointed out that acid vapors (particularly that of hydrofluoric acid) coming up from below, may decompose feldspar and yield kaolin. Deep deposits, especially if containing unaltered sulphide minerals, may have been formed in this way, and the kaolins of Cornwall, England, and Zittlitz, Bohemia, have been undoubtedly so formed. All the commercially valuable deposits of the United States, however, are of the other type, being due to ordinary weathering.

RIES, HEINRICH. *Clays and Shales of Michigan.* Geol. Surv. of Mich., Vol. VIII, Pt. I, 8vo, pp. 67, Pl. I–IV, Figs. 1–6, 1900.

That part of the work relating specifically to Michigan is preceded by chapters on the origin, properties, uses, and methods of testing clays and shales. Following these are discussions of the shales and clays of Michigan.

The important shale horizons of the state are four: the Coal-measure shales, the Michigan series, the Coldwater shales, and the St. Clair shales. The Coal-measure

shales are usually interbedded with the coal seams; though known to the miners as fire-clay, they are not very refractory. At Grand Ledge they are utilized for the manufacture of tile and sewer-pipe, and at Saginaw for paving brick. The shales of the Michigan series form a belt ten to twenty miles in width surrounding the Carboniferous area in the Lower Peninsula. They are best shown at Grand Rapids, where they form a bed six to ten feet thick overlying the gypsum. They are suited for common brick manufacture, for which they are at present used. The Coldwater shales are extensive and important, being used in all the Portland cement plants of the state. For this use they have been quarried extensively at Bronson, Union City, and Coldwater. According to laboratory tests, these shales show the properties desirable in the manufacture of vitrified wares. The St. Clair shales outcrop southeast of East Jordan. They weather to a tenacious clay and burn to a good red color. At Alpena a clay shale of the Traverse (Hamilton) series is used in the manufacture of Portland cement, and tests prove it to be suitable for the manufacture of high-grade brick.

The clays of the state are all Pleistocene, and represent three types: morainic or drift clays, lake clays, and river silts. The morainic clays are invariably calcareous, while the lake clays are very frequently so. The river silts are less likely to be calcareous, but are usually gritty. Morainic clays are used in the manufacture of pottery and brick at Ionia, Lansing, and Kalamazoo. The extensive brick clay deposits near Detroit are lacustrine in origin, while at Rockland a lake clay furnishes slip. At Sebewaing, Badoxe, Croswell, and Minden City river clays are used in the manufacture of brick.

RIES, HEINRICH, AND SMITH, EUGENE. *Preliminary Report on the Clays of Alabama.* Bulletin 6, Alabama Geol. Surv., 8vo, pp. 220, 1900.

This bulletin is divided into three sections. The first and third — entitled respectively "General Discussion of Clays" and "Preliminary Report on the Physical and Chemical Properties of the Clays of Alabama" — are by Ries; the second, entitled "Geological Relations of the Clays of Alabama," is by Smith.

The first section discusses the origin, mineralogy, chemical, and physical properties, methods of testing, mining, and preparation of clays.

In the second section the clays of the various geologic formations of Alabama are described. Under the head of "Archæan and Algonkian" the residual kaolins are discussed. A belt of mica schists with frequent pegmatite veins extends from Cleburne and Randolph counties through Clay and Coosa into Chilton county. In numerous cases the decay of the granite veins has given rise to kaolin deposits. All these deposits are distant from railroads, and are consequently undeveloped.

In the area underlain by the Cambrian and Silurian rocks the clay deposits are the residual clays left from the decomposition of the limestones of these formations, or concentrations of these residual clays by redeposition in ponds and other depressions, or accumulations in depressions of kaolins derived from the pegmatites above mentioned. The residual clays usually contain much silica and iron, and are largely used in the manufacture of brick. Occasionally, in the re-deposited clays, sorting has occurred during redeposition, and beds of very pure clay occur in consequence.

Thick deposits of pure white clay, suitable for stoneware and pottery, are found in the area underlain by the sub-Carboniferous in De Kalb and Calhoun counties. These are extensively mined, most of the product being shipped to Chattanooga, Tenn.

In the Carboniferous the clays underlying the coal seams have been utilized in the manufacture of pottery and firebrick at several points. Other Carboniferous shales are adapted for use in manufacturing vitrified and pressed brick and terra-cotta.

The lowermost division of the Cretaceous — the Tuscaloosa formation — carries important clay deposits. The strata composing the Tuscaloosa are prevalently yellowish and grayish sands, but subordinated to these are pink and purple sands, thinly laminated dark gray clays with leaf impressions, and great lenses of massive clays varying in quality from pure white-burning clays to dark purple and mottled clays high in iron. The Tuscaloosa occupies a belt of country extending from the northwestern corner of Alabama, where it is thirty or forty miles wide, around the border of the Palæozoic area to the Georgia state line at Columbus, where it is only a few miles in width. East of the Alabama river the proportion of clay to the rest of the strata is less than west of that river, and the clays themselves are more sandy. The purest clays are found in Fayette, Marion, Franklin, and Colbert counties. The clays above described have been long used for stoneware and pottery.

Fire clays are abundant in the lower Claiborne division of the Tertiary, in Choctaw, Clarke, and Conecuh counties. The Tertiary and post-Tertiary clays have not, however, been investigated in much detail.

Over the greater part of the coastal plain, in the river "second bottoms," yellow loams occur which are used for the manufacture of common brick. Lenses of pure plastic clays are also found in many places interstratified with Pleistocene sands.

In the third section Ries discusses the qualities requisite in clays designed for different uses, and gives detailed records of the tests and analyses of seventy-two Alabama clays.

SLOSSON, E. E., AND MOUDY, R. B. *The Laramie Cement Plaster.* Tenth Ann. Rept. Wyoming College Agri. & Mech, 1900.

The Laramie cement plaster is made from gypsum obtained a short distance south of Laramie, Wyo. The Triassic beds of the region contain much gypsum, one particular stratum of considerable thickness occurring near the base of the Trias, about two hundred feet above the Permian sandstone. The disintegrated gypsum from the outcropping edges of these beds has been washed down and redeposited in depressions in the plains. These gypsite deposits contain a considerable percentage of impurities, chiefly silica and lime carbonate. The Laramie gypsite bed has an average depth of about nine feet. The upper seven feet is pure gypsite, underlain by a "red layer" five inches thick, below which is a foot or more of gypsite resting on gravel and clay.

The Laramie cement plaster is made by the kettle process, the temperature being carried to 380–390° F. An analysis of it showed:

Ultimate.		Probable Combinations.[1]	
SiO_2	5.50	$CaSO_4$	73.73
Al_2O_3	0.59	$CaCO_3$	7.86
CaO	37.11	CaO	2.35
MgO	1.45	$MgCO_3$	3.04
SO_3	43.37	SiO_2	5.50
CO_2	5.05	Al_2O_3	0.59
H_2O	6.93	H_2O	6.93

The dehydration is evidently not carried far enough. Experiments show that the common cactus (Opuntia platycarpia) and malva (Malvastrum coccineum), when dried and ground, form cheap and satisfactory retarders. Tests for tensile strength show that all retarders decreased the strength of the plaster.

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